TA65A0346

SafeTrip-21 Connected Traveler: Networked Traveler Transit and Smart Parking

Final Report for Contract TA65A0346

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Executive Summary

Led by Caltrans, the Safetrip 21 Project Team developed a project proposal on "Incorporating Real-time Parking Information into the Connected Traveler Field Evaluation along the San Francisco Bay Area US 101 Corridor". The project involves efforts to (1) develop an integrated multi-modal traveler information system that covers an area along the US-101 corridor in the San Francisco Bay area; (2) recruit public users as testers and conduct a field operational test (FOT) of the integrated traveler information of real-time traffic, transit and parking availability (for selected commuter rail – Caltrain – stations); (3) support the independent and third party evaluation team to assess the system and document results from the FOT. The major objective of the FOT was to develop an integrated real-time multimodal traveler information application, and use this tool as a platform to understand the impact of real-time multimodal information and the effectiveness of real-time multimodal information on traveler behavior, especially in terms of improving travelers' perception of transit service and encouraging mode shift from single-occupancy vehicle driving to public transit.

To achieve the project objectives, the project team first conducted an analysis of the implementability and likelihood of success of the proposed integrated multimodal traveler information (IMTI) concept and the feasibility of measuring the effectiveness of how integrated multimodal traveler information would affect travelers' perception of transit service and encourage mode shift. This turned into a feasibility study of (1) selecting freeway, arterials, transit agencies and routes and parking lots as the field test site; and (2) providing integrated multi-modal information to travelers and its potential benefits in changing traveler behavior; and (3) developing measures of effectiveness (MOEs) for the field operational test.

Based on the feasibility study results, the US-101 corridor was selected as the field test site. A real-time IMTI system was then developed for this corridor to provide the following information: (1) real-time transit information for SF Muni, Samtrans, Caltrain and VTA BRT line 522; (2) real-time traffic data from freeways along the corridor; and (3) real-time parking availability information from selected Millbrae, Menlo Park, Redwood City and Palo Alto Caltrain station parking lots. The feasibility study also proposed to use both subjective and objective MOEs for evaluation. The subjective MOEs included the users' perception of usability, user friendliness of the application, as well as their perception of the provided IMTI, about its effectiveness in improving traveler information and encouraging mode shift. The objective MOEs include the accuracy of the predictive bus / train arrival time from selected routes and accuracy of parking lot detection system.

The IMTI system, named *Path2go*, integrates a web-based multi-modal trip planning tool that uses real-time information of available transit, traffic and parking availability, a web-based search tool that finds real-time transit arrival and schedule information and a mobile application that provides personalized en route transit trip information. Path2go integrates these major components of traveler information into one platform and therefore makes it easier for travelers to access real-time information.

The field operational test began on July 27th 2010 and completed on November 15th 2010. As of November 15th 2010, the Path2go application attracted over 1800 users, among which there were over 600 mobile phone users.
The project team analyzed the usage data from the Path2go system. The accuracy of the data provided by Path2go reached the design objective, where the 30 minute prediction of bus /train arrival times has a 5-precentile error.

User usage data also showed the successful operation of the system, supported by the steady growth of registered user numbers and recorded web sessions. Feedback from users showed that they positively value the information provided.
Here we quote from part of the conclusions from the independent evaluation report of the project:

> "Consumers responded positively to the NT-T/SP test, as witnessed by the number of registered users and website visits, and by the extent to which registered users provided feedback. ...
> The NT-T/SP test contributed significantly to the transportation industry's collective understanding of distributing real time transit information. The test demonstrated the ability to integrate transit, traffic, and parking information across multiple agencies in real time. The test highlighted the potential for distributing personalized information via the internet and smart phones, and to do so without causing driver distraction. ...
> Well over half of respondents "strongly agreed" or "agreed" that the information was valuable and this is contrasted with only 14 percent who "strongly disagreed" or "disagreed." In fact, when using the applications, respondents felt that having information for multiple transit services was very useful.
> Additionally, there was relatively strong agreement from respondents that the real-time departure and arrival information supplied on the application was valid."

Major MOEs of the NT-T/SP operational test and their documented results are listed in a table on the next few pages.

Table ES-1: MOEs and Measured Performance

Expected Test Outcome and Traveler Responses	Measures of Effectiveness (MOE)	Expected Performance	Measured Performance
Public awareness of the applications	• project participation: Project Partners	• N/A (qualitative MOE)	• CCIT, ParkingCarma, Navteq, SamTrans, VTA
	• Scope of participation by partners	• N/A(qualitative MOE)	•
	• List of participating organizations outside of project team	• N/A (qualitative MOE)	•
	• Scope of community participation o Number of participating users o Number of data samples collected in field tests	• Enough users so that usage and survey result data can result in meaning statistics (e.g., error margin less than 10%)	• Participated Users: 783 mobile users; • Web users: over 1000; • Error margin for survey results: less than 10% • achieved √
	• Outreach efforts o Sessions of activity reports held in public forums and conferences o Technical papers presented o Reports of media events	• N/A (Qualitative)	• Four technical paper presentation (2 on ITS World Congress 2010, 2 on TRB Annual Meeting 2011) • Won Outstanding paper award on ITS WC 2010 • Berkeley Press Release • Media Reports (See 5.5 for details) (See Appendix F for more details of the outreaching efforts)

Expected Test Outcome and Traveler Responses	Measures of Effectiveness (MOE)	Expected Performance	Measured Performance
Favorable user experience and positive user feedback to the multi-modal pre-trip planner and mobile application	o Willingness to participate and to maintain continual use of the applicationNumber of participating users o Periods of active usage o Continuity and frequency in activating applications	• Frequency usage of the application • Steady growth in the users and numbers of usage • Time on site / mobile application	• Results are based on analysis from objective usage data (two data sources: Server logs and Google Analytics results. Analysis showed results from the two data sources were consistent) A. Steady growth of number of users during the FOT (Independent Evaluation report, 2011) B. Steady usage of web and mobile application with fluctuations (overall usage grew steadily) , (Independent Evaluation report, 2011), see also 5.6.5 for details C. Relatively low returning users, however as pointed out by the evaluation report, this is expected behavior for web / mobile phone applications. √
	• User feedback to surveys and questionnaire on - Functional usefulness - Functional acceptability - User interface friendliness - Information accuracy (in terms of predicted parking space availability, predicted train arrival time, etc);	• Favorable feedbacks to the survey questions	• Results are based on the voluntary survey collected on the project website during the FOT and the final survey after project finished. ***Overall Evaluation***: √ Good (66.7%) Neutral: (27.5), only 5.9 bad ***Usefulness of information***: √

Expected Test Outcome and Traveler Responses	Measures of Effectiveness (MOE)	Expected Performance	Measured Performance
			Over 70% agree/strongly agree Path2go is useful. Less than 6.0% disagree /strongly disagree. (Final survey 56%-65% versus 14%-10%) ***Information Accuracy***: √ 66% agree/strongly agree versus 6% disagree/strongly disagree (Final survey: 40% versus 12%) ***Helps to reduce waiting time at bus / train stop***: √ 74.6% agree/strongly agree, versus 9.8% disagree /strongly disagree. ***Encouraging Mode shift (Consider Transit as more viable option)***: 64% agree/strongly agree versus 6% disagree/strong disagree Likelihood for mode shift: (32.1 % yes versus 29.5% no) There was one aspect that received relatively low user perception, which is the user interface design and usability. Higher percentage of survey respondents indicated that the

Expected Test Outcome and Traveler Responses	Measures of Effectiveness (MOE)	Expected Performance	Measured Performance
			information was not very well organized.
Mode shift actions by users: "Park and ride" alert and CMS information (No longer applicable after the rescoping of the project)	• User Mode shift actions • Frequency of user activating the application of "Park and Ride" alert; Percentage of samples when a mode shift is seen after "Park and Ride" alert is given to the traveler; • Percentage of users (based on survey data) ever shifted / or would shift mode upon seeing each CMS information ; Time saving preferences to switch mode (from user perspective)	• N/A (dropped after rescoping)	• Dropped after rescoping We still have such a question in the final survey and the result is : ***Have you ever changed your route***: 13.3% yes, versus 86.7% no.
Objective information accuracy	• Accuracy of bus /train arrival time prediction results • Accuracy of the encoded parking space availability information	•	• **Good results achieved for** Arrival Time Prediction accuracy: √ o on average about 0.6 minute for predictions over 10 minutes before the arrival at the stop. The 75 percentile error is less than 1.7

Expected Test Outcome and Traveler Responses	Measures of Effectiveness (MOE)	Expected Performance	Measured Performance
			minutes (VTA buses) o on average less than 0.5 minute error for prediction over 10minutes before the actual arrival, 1.5 minutes over 20 minutes before arrival (SamTrans bus routes) • Good results for accuracy of parking availability data √ o Counting error: 1% over 2 weeks of testing o Overall error (calibration error of overnight parking): average less than 3% • Accurate Arterial performance measure results: o Travel time: RMSE 9%, o Level of service: accuracy 73%
Geofencing functionality	Verify that Geofencing functionality is implemented and works to prevent usage while driving	Testing under certain predefined scenarios to verify for each scenario whether or not the geofencing logic can successfully identify the situation	A total of 20 trips were made during testing. Geofencing successfully detected 19 trips out of 20. The failed trip was because there was a bus following the car. √

Expected Test Outcome and Traveler Responses	Measures of Effectiveness (MOE)	Expected Performance	Measured Performance
		and behave properly.	

There have also been major lessons learned from the NT-T/SP project. (1) The first lesson involves the management of the risk of integration of data from multiple agencies for system interoperability. The integration effort was complicated from the following two perspectives: the technical difficulty due to the lack of standardization in real-time data and the institutional issues caused by the complicated arrangements to obtain the data, which was made additionally complex when certain communication systems vendors could own part of the database. (2) Another major lesson learned is understanding the complexity of the geofencing concept and its compromise of usability. Publicly-recruited users found the design of the 'disabling' display not desirable. The occasional false warnings, due to the inherent limitation of the user-activity detection method based only on GPS data, was also found to be annoying to users. Finally, (3) to understand public users' needs is another lesson learned from the FOT. Although the application website has clearly identified the Path2go application as a pilot research tool, it is nevertheless considered to be a public service and product by the recruited users and then compared to other publically available tools. This expectation apparently imposed a high quality requirement for the usability design, which was not the emphasis during the project development phase of the project partly due to the tight schedule and the delay caused by other issues such as the institutional arrangements.

1. Introduction and Literature Review

1.1. Introduction to Networked Traveler Transit and Smart Parking

US DOT's Research and Innovative Technology Administration (RITA) launched the Safetrip-21 program as a near-term component of USDOT/RITA's Intellidrive program, to "*explore the applications of ITS technologies that transfer information on traffic and travel options to and from vehicles to reduce congestion and increase safety, mobility, efficiency, and convenience*." (Bell, Dinning, Kay, Ritter, Smith, & Steward, 2008). One important aspect of the Safetrip-21 program is to seek out ITS technologies that can make public transit a more convenient option.

The Volpe Center entered into a cooperative agreement with the California Department of Transportation (Caltrans) to establish a SafeTrip‑21 field test site in the San Francisco Bay area, called the California Connected Traveler test bed, one of the two test beds awarded nationwide.

The California Connected Traveler test bed is comprised of three components:

- ***Networked Traveler Transit/Smart Parking***: The contents of this report, NT-T/SP involves developing a real-time multi-modal trip planning and traveler information application for the US-101 corridor in the San Francisco Bay Area and conducting a field test and evaluation based this application. The major objectives of NT-T/SP is to develop an integrated real-time multimodal traveler information application, and use this tool as a platform to understand the distribution of real-time multimodal information and its effectiveness on traveler behavior, especially in terms of improving travelers' perception of transit service and encouraging mode shift from single-occupancy vehicle driving to public transportation.
- **Networked Traveler-Foresighted Driving:** This application is about the study of safety alerts for upcoming slow traffic ahead;
- **Mobile Millennium**: This application is about using GPS-enabled smart phones to generate real-time traffic information.

Toward the end of 2009, the NT-T/SP project was re-scoped to address concerns on distracted driving caused by using mobile phones while driving. As a result, a planned feature on the mobile phone was removed. Previously it was planned to provide mobile phone alerts to the driver of upcoming traffic congestion and recommending an alternative park-and-ride option. The project then became more focused on the web-based pre-trip planning and the mobile application became transit-only. A "geofencing" module was also added to prevent users from using the applications when they are detected to be more likely driving.

There have been two stages of the NT-T/SP project. The first stage is the system integration and major application development stage when the multimodal real-time information application was developed and tested. The application was later named *Path2go*. The second stage is the field operation test (FOT) with a national independent evaluation carried out by Science Application International Corporation. The public FOT was started on July 27th 2010 and was completed on November 15th, 2010. Then California PATH worked with the independent evaluation team to provide objective data for evaluation purposes and coordinate user surveys. The Path2go application has been kept operational even after the FOT ended.

1.2. Literature Review of Multi-modal Traveler Information System

Traveler Information Systems (TIS) can be categorized into two generations as suggested by Adler et al in (Adler & Blue, 1998), with the first generation consisting of variable message signs, route guidance systems, and the second generation (advanced traveler information systems [ATISs]) usg new technologies to provide dynamic route guidance, real-time traffic conditions, and en route traveler information in an integrated manner.
While the TIS technologies have been developed, there is still a deficit in the expected benefits from these systems. Several studies have addressed this issue, including one conducted in Seattle (Pierce & Lappin, 2004), which showed that the critical factor that prevented the ATIS from being effective is the availability, level of detail and accuracy and timeliness of information. Other critical factors include the awareness of the sources and nature of the trips.

To improve the availability of the information, state-of-the-art traveler information systems have adopted web and mobile phone platforms. The use of these technologies is considered to be cost-effective for the agencies operating the services and therefore the most preferred way of delivering the information. In 2008, Internet users in the United States reached 230 million (World Bank, 2009); also mobile phone users in the United States reached over 280 million at the end of 2009 (CTIA-The Wireless Association, 2009). It is clear that a web-based and mobile traveler information system could significantly improve the accessibility of the information.

Improving data quality by providing real-time transit information is another means to appeal to users. Real-time transit arrival time predictions based on automatic vehicle location (AVL) systems technology have significantly improved transit data quality. More accurate real-time data helps to relieve traveler stress and reduces the waiting time when provided a priori to the traveler. An increasing number of agencies are providing such information, including the Bay Area Rapid Transit (BART), Chicago Regional Transportation Authority (RTA) (RTA), and dozens of transit agencies and schools whose systems are powered by NextBus ® (Nextbus). Travelers can benefit from better information quality by receiving real-time transit information. This is true even for infrequent or choice transit users, who are a key market for attracting more transit riders. A primary approach to encourage mode shift is to provide multiple travel options to these travelers. Kenyon and Lyons from Southampton University conducted a survey which showed that presenting a number of modal options for a journey would help travelers consider alternative modes (Kenyon & Lyons, 2003). State-of-the-art traveler information systems, therefore, have provided multi-modal traveler information. Google ® Transit is a convenient tool for travelers to compare driving, transit, walking and bicycling. Another well-known system is the Goroo system of Chicago RTA, which provides a multi-modal trip planner for the Chicago metropolitan area with real-time transit information. Networked Traveler aims at integrating multimodal trip planning, together with real-time information from transit, traffic and parking, to provide the users with a more integrated multimodal information tool.

1.3. Relevant Previous Smart Parking Projects

Smart parking systems may generally be defined as systems that use advanced technologies to assist motorists in locating, reserving, and paying for parking. These smart parking systems customarily provide real-time information by means of changeable/variable message signs to motorists about the number of available parking spaces in park-and-ride facilities, departure time for the next transit vehicle (bus or train), and downstream roadway travel conditions from the park-and-ride facility, including incidents, time delays, or comparative travel times. The primary objective of implementing such smart parking systems is to increase the mode share for transit by changing the travel behavior of motorists for at least a portion of their trip from the single-occupancy-vehicle mode to the public transport mode. Accompanying such behavioral changes could be transit revenue increases, reduced vehicle-miles-traveled, increased person-miles-traveled, reduced energy consumption, and reduced air pollution including green-house gas emissions.

Smart Parking Systems have been implemented in Europe, Japan, and more recently, in the U.S., to help efficiently manage parking capacity at park-and-ride facilities/transit stations. In Europe, such systems are located in numerous cities and regions including the following cities in Germany: Berlin, Cologne, Frankfurt, Stuttgart, and Dortmund; in Geneva, Switzerland; the French cities of Chambery, Grenoble, Lyon, and Strasbourg; in England, the English cities of Nottingham, Southampton and York; and in Dublin, Ireland (Orski, 2003).

One of the most advanced systems in Europe is the Cologne system, called *Stadtinfokoln*. It is described in (Orski, 2003) as providing

> "*up-to-the-minute information about parking availability both at suburban park-and-ride lots and at the 31 affiliated underground and surface parking facilities in Cologne's city center. This information is displayed on automatically updated variable message signs situated on approaches to the city, enabling city-bound motorists to decide in advance if they should leave their car at a suburban park-and-ride and complete their journey by train, or continue all the way by car. Drivers who decide to drive all the way into the center are guided to parking facilities that have vacant spaces with the help of directional signs that display the number of vacant spaces available at any given time.*"

The parking guidance information sub-system uses loop detectors to monitor available parking spaces in facilities and transmits information via variable message signs. Moreover, historical data by time is used to predict parking facility occupancy status.

Another example in Germany of an advanced parking information system is in Munich at the Frottmaning U-Bahn station park-and-ride lot with 1,270 parking spaces off the A9 Autobahn. Three dynamic variable message signs along the highway provide the number of parking spaces, real-time transit schedules and traffic conditions. Once in the parking facility, motorists are guided to the closest available parking space by a real-time surveillance and control system. An evaluation of the Munich advanced parking information system showed that highway park-and-ride signs were the main reason that motorists shifted from driving to taking the train to work (Cervero, 1998).

In Japan, an application of a smart parking system is in the city of Toyota, considered Japan's "Detroit". The system was developed to support park-and-ride lots at the city's two major transit

stations. Information on parking and downstream traffic conditions is collected and provided to drivers by telephone, variable message signs, radio, and entrance signs at parking facilities (Sakai, Goto, Sugimote, & Okuda, 1996). In this case a survey was performed six months after operation began and showed that 95% of respondents were aware of signs; 71% made use of information; and 87% thought the system was helpful.
In (Khattak & Polak, 1993) the authors systematically evaluated, using survey methodology and in-person interviews, the effectiveness of smart parking systems relative to increasing park-and-ride facilities in Nottingham, England. This evaluation suggests the importance of pre-trip information with respect to parking choice and transit use.

Between December 2004 and April 2006 a Smart Parking System Field Operational Test (FOT) was conducted at the Rockridge Bay Area Rapid Transit (BART) Station in Oakland, California in the San Francisco Bay Area (Shaheen & Rodier, 2006). This field test was, at the time, the first transit-based evaluation of a smart parking project in the U.S. The remainder of this section highlights the primary report deliverables on the Rockridge BART Station Smart Parking system Field Operational Test with emphasis on travel behavior impacts resulting from using the Smart Parking system.

We note that although there have been a few previous efforts made on smart parking projects, there is still a need to integrate real-time parking information with the multimodal traveler information system and examine the effectiveness of the information as whole, which is one of the motivations of the NT-T/SP project.

2. Feasibility Analysis

2.1. How Integrated Travel Time and Parking Information can Encourage Mode Shift Along the US 101 Corridor?

2.1.1. Existing Corridor: Scope and Characteristics

The San Francisco Bay Area is the fifth most populated metropolitan region in the United States. The US-101 corridor is centrally located within this region and is a vital route, providing connectivity between the Bay Area's two largest cities, San Francisco and San Jose. It features densely populated residential areas and many major commercial and industrial centers located along the corridor. Throughout the corridor, route and modal alternatives abound: a major arterial, State Route 82 (El Camino Real) and commuter rail – Caltrain – service run parallel to US 101 and I-280 through the corridor. The Bay Area Rapid Transit (BART) system also runs parallel to US 101, with its southern terminus being Caltrain's Millbrae station. Moreover, the Santa Clara Valley Transportation Authority (VTA) and the San Mateo County Transit District (SamTrans) operate buses that cover the entire service area along the US 101 corridor. In fact, VTA operates transit buses in the greater metropolitan San Jose region and their northern boundary ends in Palo Alto, and SamTrans operates transit buses extending from south of Palo Alto, then northward all the way into San Francisco. In the vicinity of Palo Alto, the two jurisdictions overlap, and SamTrans and VTA share some of the same facilities.

A. Freeway - US 101 and I-280

According to the Metropolitan Transportation Commission (MTC), US-101 is one of the most congested highways in California. Figure 2-1 shows the aggregated speed contour along northbound US-101 from East Palo Alto, CA to the interchange with I-280. The contour is plotted based on the freeway loop detector data collected by the Freeway Performance Measurement System (PeMS). The data covered the morning commute peak (6AM to 10AM) for typical weekdays, i.e. Tuesday, Wednesday and Thursday, for a period of three weeks (09/23/2008 to 10/09/2008). As highlighted in Figure 2-1, there are three major bottlenecks in this part of US101: the Dumbarton Bridge in Palo Alto, the San Mateo Bridge in San Mateo, and the interchange with I-280 in San Francisco. Among the three bottlenecks, the interchange with I-280 has the longest and most severe impact on aggregated average traffic speed. The congestion area is longer than one mile and lasts for almost the whole morning peak period. During this time, traffic peaked approximately at 8:30AM with traffic being stop-and-go. The second most congested area is in Palo Alto, peaked at approximately 7AM, and lasted for about two and a half hours.

For commuters whose destination is San Francisco, their freeway trips typically end onh I-280 between the interchange with US-101 and King Street. As illustrated by Figure 2-12, the recurrent traffic congestion is not as severe as that on US-101. But there is still a significant speed drop at 7AM. The congestion will normally be cleared by 9AM.

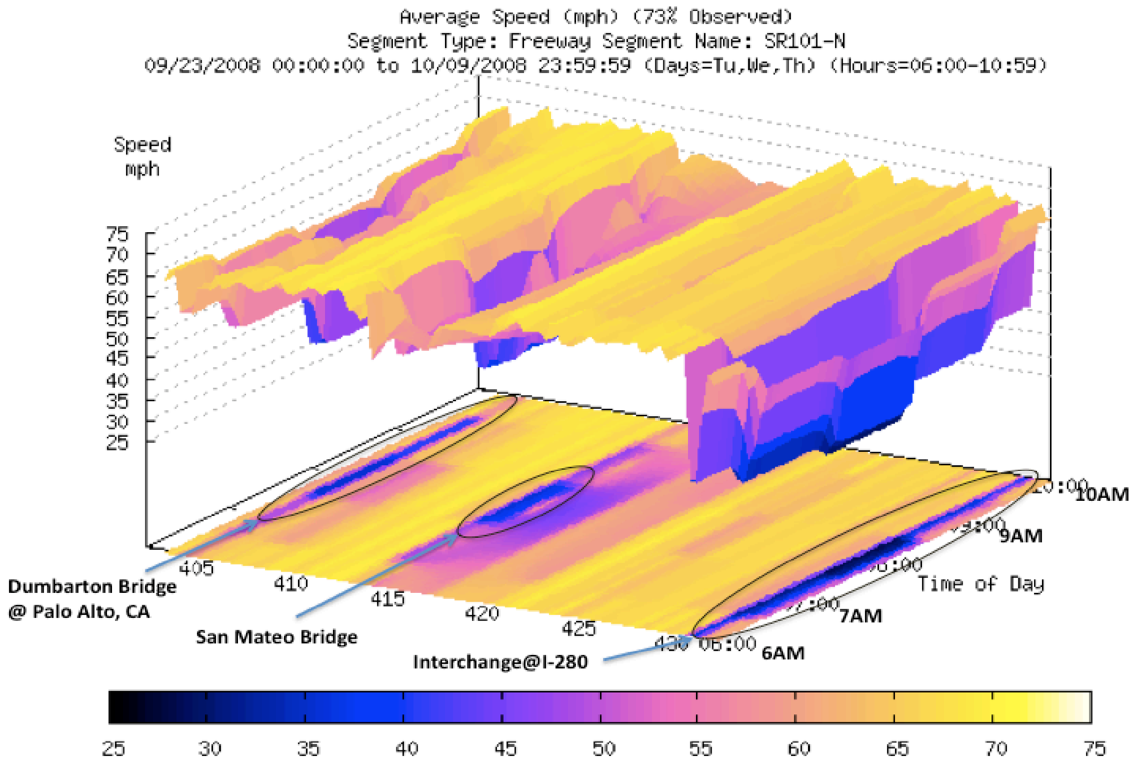


Figure 2-1 Aggregated Speed Contour along Northbound US-101

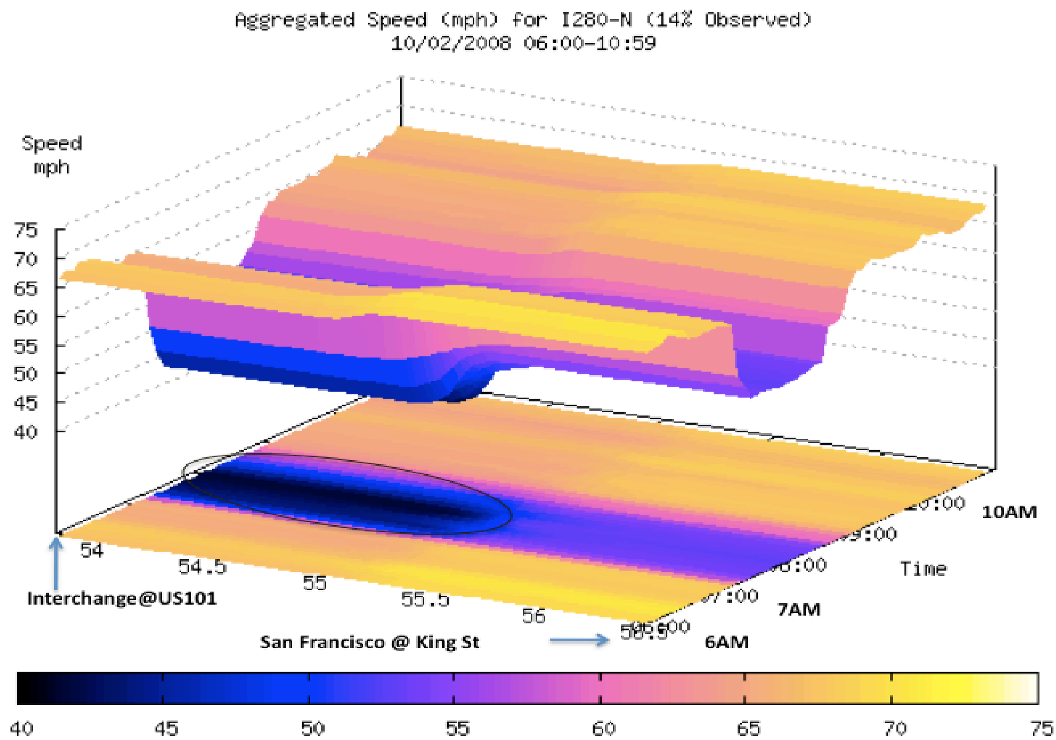


Figure 2-2 Aggregated Speed Contour along Northbound I-280

B. Major Arterial – SR 82

There are a few parallel arterials along the US-101 corridor. State Route (SR) 82, also known as El Camino Real, is the longest arterial running parallel to US-101 and carries significant volumes of local area traffic. Although the traffic signal lights are well coordinated along SR82, drivers still need to make stops at every few traffic signals particularly during peak hours. Therefore, commuters typically will not choose this arterial unless special events or incidents happen on the two parallel freeways.

C. Caltrain Services

The aforementioned commuter rail service is Caltrain, which is managed by the Peninsula Corridor Joint Powers Board (JPB) under the organizational umbrella of SamTrans. Caltrain operates 98 weekday trains between San Francisco and San Jose, with nearly 44,000 daily riders. Service with approximately 15-minute headways occurs during the morning and evening commute peak periods, with half-hour to one-hour headways during non-peak periods. Most Caltrain stations either adjoin or are within a quarter mile of El Camino Real and importantly, provide all-day parking for riders. As an additional note, according to their 2006 annual ridership count, Caltrain runs with approximately 20% of its seats empty. Caltrain operates three types of services: a local train which stops at every station, a limited train with stops at a limited number of stations and its Baby Bullet trains with stops at 5 major transfer stations only. During the morning and evening peak period, only limited trains and Baby Bullet trains are in service.

D. Caltrain Parking Facilities

Twenty Caltrain stations have parking facilities with a total of 5,711 available parking spaces. Two surveys of all these parking facilities were conducted by PATH on September 24, 2008 and November 20, 2008. The 9/24/08 survey showed 10 out of the 21 parking facilities operate at or near capacity (> 80%) at noon, and all parking at stations served by the “Baby Bullet” (express) trains to San Francisco were at or near capacity. However, the other 11 lots had excess capacity. The total number of available spaces at Noon was 1,277. Notably, among the parked vehicles, over 100 vehicles were parked illegally. The 11/20/08 survey showed quite different results. Only 6 out of the 21 parking facilities operate at or near capacity (> 80%) at noon. All parking at stations served by the “Baby Bullet” (express) trains to San Francisco was at or near capacity. The other 15 lots had excess capacity, with a total of 3,084 available spaces at Noon.

2.1.2. Analysis of the Potential Influence of Integrated Travel Information on Travelers

The US-101 corridor is a typical commute corridor that has many transportation options, including driving on freeways and arterials, and riding commuter rail, transit rail, and buses. As previously stated, the freeway system along the corridor is severely congested during peak periods. Meanwhile, transit and parking facilities along the corridor have not been fully utilized. The addition of parking information for transit stations would provide travelers with a complete and integrated set of information. Given such information, travelers can potentially make smarter travel decisions.

In addition, real-time traffic conditions play an important role in assisting drivers to make the mode shift decision dynamically. The US-101 corridor is well instrumented to provide this information, either from MTC's 511 FastTrak travel time estimation or directly from Caltrans' sensors located along the route.

Once the integrated and dynamic information is ready, the next question is posed: can such information indeed benefit travelers for their daily commute trip? In order to analyze the influence of integrated travel information on travelers, we assume a morning commute trip starts from the Palo Alto area and ends in San Francisco. Palo Alto is a major transfer station and all three types of trains stop at this station, and it is used as a case study site.

According to the published Caltrain schedule, the travel times and service headways are illustrated in Table 2-1. If we consider the commute trip starts from south of Palo Alto, the traveler can drive all the way along the highly congested US-101 and then I-280. Alternatively, since real-time parking space information for the Palo Alto station together with train arrival time information are readily available for the traveler, he/she now can take advantage of the underutilized commuter rail service (Caltrain). For this specific example, we can make an explicit comparison between the two transportation modes.

Table 2-1 Caltrain Service from Palo Alto, CA to San Francisco, CA

Unit: Minutes	Service Headway	Scheduled Travel Time	Mode Shift Time	Parking and Transfer Time	Trip Travel Time
Local Train	30	60	6	3	69
Limited Train	30	44			53
Baby Bullet Train	30	38			47

When taking train service, the traveler can take the US-101 off-ramp at University Ave. and travel about 6 minutes to the Palo Alto Caltrain station. Parking takes another three minutes before he/she is able to get to the platform, then he/she can take one of the three Caltrain services, simply relax or do work while enjoying the comfortable train ride.
In comparison, the traveler might take US-101 and merge onto I-280. According to historical loop detector data and electronic toll collection (ETC) toll tag data from PeMS and MTC, the average trip travel time from Palo Alto to San Francisco varies from approximately 30 minutes to over 65 minutes. Figure 2-3 illustrates the travel time for both driving and taking different train services in the morning on a typical weekday. In the very early morning when traffic is not too bad, average travel time by driving is about 35 minutes, which is about 12 minutes faster than taking the Baby Bullet train. After about 6:45AM to the end of the morning peak, driving time is comparable with travel time by the limited train service and longer than that by the Baby Bullet trains. Local train service is not a viable option for commuting trips as it does not run between 5:36AM and 9:41AM. Between 6AM and 10AM, the limited and Baby Bullet trains combine for a frequent commuter rail service with headways of only fifteen minutes. More importantly, rail service is not taking a longer time than freeway driving and can even save some time for travelers between 7:30AM and 10AM.

Similar results can be obtained for comparing limited train travel and freeway travel at non Baby Bullet train stations. A further case analysis revealed that Caltrain's existing schedule offers the possibility of time savings for travelers who get on limited trains at a nonBaby Bullet station to transfer to a Baby Bullet train at a forward Baby Bullet station. Table 2-2 provides two examples that illustrate travelers who initiate trips from non-Baby Bullet stations prior to

Hillsdale who can make take a limited train and transfer to Baby Bullet train at Hillsdale, which would allow them to arrive at San Francisco 6 minutes earlier than the limited trains do. Other case examples show that this time savings can go as high as 17 minutes. We believe that the Caltrain schedule can be further optimized to better consider the 'transfer riders'.

Table 2-2 Possibilities for transferring between limited trains and Baby Bullet trains

		Case Example 1		Case Example 2	
		Regular	Baby Bullet	Regular	Baby Bullet
Trip ID		211	313	221	323
Station Names & Time	Hillsdale	7:02	7:16	8:02	8:16
	Millbrae	7:17	7:24	8:17	8:24
Final Station	San Francisco	7:48	7:42	8:48	8:42

While the parking lot surveys indicate that the parking lot at the Palo Alto station has been consistently full by noon, the parking facilities at stations adjacent to the Palo Alto station are available. While travel time using the limited train at the California Ave and San Antonio Ave stations is typically similar to that of freeway travel, the 'transfer' analysis provides opportunities for travelers with time-saving options to park their vehicles at these non-Baby Bullet train stations and use a combination of limited train and Bay Bullet services for their commute.

In summary, integrated and dynamic traveler information has the potential to influence travelers to choose transit in the discussed scenario not only by saving time but also by enhancing the pleasure of the trip.

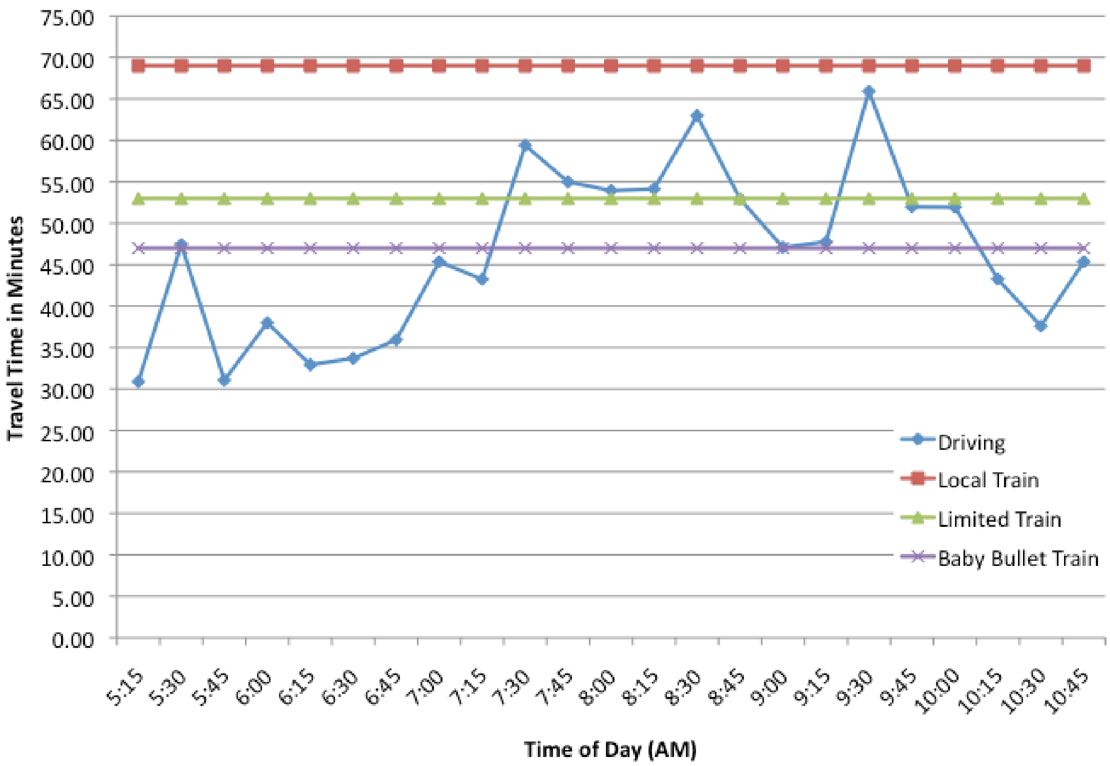


Figure 2-3 Trip Travel Time Comparisons among Different Transportation Modes (morning peak from Palo Alto, CA to San Francisco, CA)

In the design of the Path2go application, we have taken into account the consideration of this feasibility analysis by providing a comparison of different travel times for different modes (driving, driving-to-Caltrain, transit) at a glance to help travelers make informed decisions. Emissions savings of transit related modes are also emphasized in the Path2go web-based pre-trip planner to encourage mode shift, and a similar effort was also adopted to color code different modes to emphasize the fact that travel time on transit can be for "working and relaxing".

Test results showed that a significant amount of users considered the integration of multimodal traveler information valuable and would make them more likely to take transit. More details can be found in Section 5.6 FOT Data Analysis of this report.

2.2. Measuring Benefits Provided by a Multimodal Traveler Information System

An FOT was conducted along the US-101 to measure the benefits provided by an integrated multimodal traveler information system. Public users were recruited to use the application and their usage data were stored for analysis. Furthermore, users were also invited to take surveys, from which data were also part of the FOT data analysis.

The analysis of the FOT data was led by the independent evaluator team led by SAIC. The project team provided data for this evaluation effort. In addition, the project team worked with the evaluator to develop an evaluation methodology suitable for the field test.

In order to understand how well the multimodal trip information system works and the impacts of this system on passengers' travel mode shifts, regional traffic congestion, and air quality, the *objective evaluation* using field data were focused on the following:

(1) System functionality – Is the planned trip information as accurate as expected?
(2) System performance
    a. Parking and transit service – Is the system providing measureable improvement on parking lot usage and transit ridership?
    b.
    c. Is the information considered accurate, timely, helpful and effective?

Table 2-3 Details of the Description of the Measurable Benefits

Measuring Benefits		Details
System Functionality		Described in Section 5.4 System Testing and Performance Analysis
System Performance	User perception of the information	Described in Section 5.6 FOT Data Analysis.
	Measurable improvements in Parking Usage and Transit ridership	N/A

Detailed MOEs for system functionality should be both quantitatively assessable and qualitatively acceptable by passengers. We learned from the Rockridge Smart Parking project, the US-101 parking information project, and the on-going San Diego Smart Parking projects how to improve the MOEs. Specifically, both quantitative and survey evaluation approaches used in the existing US-101 travel time/parking information project directly benefit this study. The survey study conducted under the Rockridge Smart Parking project also served as a reference for subjective studies.

We will introduce the detailed MOEs in Section 5 Field Operational Test of this report.

2.3. Analysis of Technologies and Products that Prevent Distracted Driving

In November 2009, the project was re-scoped due to concerns regarding the usage of cell phones while driving and the issue of driver distraction. One important aspect as a result of the re-scoping was including the feature of "geofencing" that can help to prevent the usage of the application while the user is driving.

In this section we investigate the existing technologies and products for distracted driving.

The primary method to collect information on driver distraction and geofencing involved a comprehensive search of the Internet. The Federal Communications Commission's (FCC) Distracted Driving Information Clearinghouse website (http://www.fcc.gov/cib/driving_clearinghouse.html) lists 15 different products that help with reducing the dangers of distracted driving. We also investigated other products and technologies that we found from our Internet search.

We group various geofencing products by the technologies used and the distracted driving scenarios for which they are helpful. Application scenarios are compared to the needs of the Networked Traveler project.

The existing technologies used by those products do not have the capability to differentiate driving from taking transit, based on a user's GPS trace data therefore they would be hard to fit into the needs of the Networked Traveler project by using these products only. Thus it was necessary to develop a geofencing function into the networked traveler application that can identify a user's travel mode, i.e., driving versus taking transit). Nonetheless, the technologies of the existing products can still be helpful to reduce distracted driving.

2.3.1. Background

Geofencing is a term that originally referred to a practice of limiting mobile employees to a specific geographic location by tracking their whereabouts via the technology of a GPS. Most initial geofencing applications involved server-based functions, including:

1) Fleet management
2) Child and elderly location awareness
3) Asset (e.g., vehicle) tracking
4) Vehicle security

The **Cell Phone Geofencing** concept has recently been developed and involves the use of a GPS signal together with data from an automobile indicating that the user of the phone is driving, and disables use of the phone under these conditions.

Under the **Networked Traveler (NT)** Project, though the 'geofencing' term has been borrowed, it is extended beyond its original and cell phone-related definitions. NT geofencing refers to a function that identifies the types of vehicles in which the cell phone is located (automobile or transit vehicle), and disables the NT applications (i.e., trip planning, next bus/train, and arrival notification) when the cell phone is detected to be likely in a moving automobile, while allowing the application to function when the cell phone is recognized as being located in an identified and located transit vehicle, in a designated transit parking area, or in a building rather than in a non-transit vehicle moving along a roadway.

This report provides a summary of commercially available **cell phone geofencing** products and services and a brief description of the NT geofencing technology developed under the Networked Traveler Project.

2.3.2. Commercial geofencing products and services

A. Location based

The location-based service (LBS) enables a location-aware device to receive notification about the location of a device when its user enters or exits a geofenced area. The geofencing notification can be sent to a mobile telephone or an e-mail account. The following commercial products and services are available:

Zentracker (www.zentracker.net): Zentracker uses Google Latitude to enable its clients to track a cell phone user using a combination of GPS, WiFi network, and cell ID positioning (cell tower triangulation). In order to track a cell phone user, the user must have Google Latitude software installed on his or her smart phone. In terms of geofencing, Zentracker can establish a perimeter in Google Latitude by mapping its GPS coordinates. When a user leaves the geofenced area, zentracker.net will notify its clients via twitter, e-mail, SMS, or Facebook. In addition, Zentracker allows its clients to track up to six smart phone users simultaneously.

PlaceCast (www.placecast.net): PlaceCast uses geofencing to draw consumers to location-specific businesses. PlaceCast establishes a geofencing perimeter around the location of a business and whenever a consumer enters the geofenced area, he or she receives advertisements for that particular business via a device (smart phone). The cost of this service depends on the volume of advertisements sent to consumers.

ShopKick (www.shopkick.com): ShopKick is a smart phone application that gives users reward points and special offers when a user enters a store or business area. ShopKick uses a combination of GPS, WiFi, and sensors to detect users in a geofenced area.

B. Geofencing technologies using speed and location

This category of geofencing products monitors GPS speeds and location in real-time and records dangerous behavior for later review; some can even send alerts to a server or a third party. The following commercial products and services are available:

CellSafety (WebSafety) (www.websafety.com/cell-safety): CellSafety is a software-only solution that provides parents the ability to monitor almost every aspect of their children's use of smart phones, including driving speed and location history. It also prevents the usage of a phone while it is detected to be moving faster than a certain speed by disabling phone calls and text messaging. The solution uses GPS and 3G communications to transfer real-time information from the child's phone to the main data center, and to forward it to the parent's smart phone via e-mail or text notification. CellSafety software is compatible with BlackBerrys, Android phones, and Nokia S60 phones.

DriveAssist (www.aegismobility.com): The DriveAssist mobile client runs in the background of a user's smart phone. It uses GPS and other sensors, along with algorithms based on movement of the mobile phone, to determine whether the user is driving. The service automatically activates when driving is detected and usage of the mobile phone is restricted except for emergency calls, enabling the driver to focus on the road. Once the service detects that the user has stopped driving, it automatically deactivates. The solution is designed with various optional features that can be customized based on the user's needs.

Guardian Angel MP (http://www.trinitynoble.com): This product is a phone-based application that locks the keys of a cell phone while a vehicle is traveling above a certain speed. Guardian Angel MP can tell the difference between the cell phone of a driver and the cell phone of a passenger (requires an external GPS receiver).

iZUP (www.illumesoftware.com): iZup is a mobile application developed by Illume Software that helps a driver avoid distractions caused by his or her mobile phone. When the application is turned on, iZUP utilizes GPS signals to detect when the phone is traveling faster than five miles per hour. It shuts off almost all functions of the phone at higher speeds except for emergency 911 calls. Even when the vehicle is stopped, the iZUP application allows only a few seconds for the user to make calls or text. It is available on both Android and BlackBerry platforms.

PhonEnforcer (http://turnoffthecellphone.com/): Automatically turns off the phone when the user is driving. Available as a software application for Windows Mobile phones, Android phones and Blackberry phones. PhonEnforcer uses GPS technology.

Teen Tracker (Apple Apps Store): Teen Tracker is an Apple iPhone application that tracks movement of teenagers through their phone. The application is installed in both the parents' and the teenager's phone. Though the marketed functions are geofencing-specific, products of this kind have the capability to trigger warnings based on preset geofenced areas (areas that drivers are not allowed to enter or leave).

TxtBlocker (www.txtblocker.com): TxtBlocker is very similar to iZUP in terms of functionality. The software is currently available only for the BlackBerry platform, but according to its website, they plan to be compatible with the iPhone, Palm Pre, and Android phones in the near future.

C. Geofencing technologies that use on-board device to prevent distracted driving

This category of geofencing products detects cell phone use while driving and disables the cell phone functions. The following commercial products and services are available:

CellControl (www.cellcontrol.com): CellControl is very similar to Key2SafeDriving, using software and hardware that disables smart phone use while driving via Bluetooth communications and software. The software works on most HTC, Motorola, Nokia, Pantech, BlackBerry, and Samsung smart phones.
http://www.aegismobility.com/
Key2SafeDriving (www.key2safedriving.com): Key2SafeDriving uses both software and hardware solutions to disable the use of a smart phone while driving. Developed by the University of Utah, Key2SafeDriving has two parts: (1) a device that is plugged into a car's on-board diagnostic system, and (2) software that is installed on the cell phone. When the car is turned on, the device automatically disables the smart phone via Bluetooth communications. Key2SafeDriving does not use GPS. The user is limited to making only emergency calls. The software supports a limited number of major brand smart phones, including BlackBerry, HTC, Nokia, and Samsung. A list of supported smart phones can be found at http://www.key2safedriving.com/phonelist.html.

OCK (Try Safe First Inc.): The OCK is a unique two-part automotive and cell phone safety device designed to eliminate cell phone driver distraction. The device includes a downloadable cell phone application along with two sensors installed in the car. Whenever the car is started and in gear, a signal is sent to the cell phone to disable either texting or e-mailing, or all functions of the phone.

Signal Safe (http://www.nodriverdistraction.com/Home_Page.php): For this product, a device is installed in the car to issue a visual warning to the driver whenever there are phone calls or text messages from the cell phone of the driver (on the driver seat). There is no embedded software in the cell phone.

SimpleTrack (http://www.drivertelematics.com/pages/profile.html): For this product, a device is mounted in the diagnostic port under the dashboard. This system monitors risky driving habits, such as speeding, hard braking, and acceleration, and the data is transmitted in real-time to the safety data center. Instant alerts are also sent out to parents via text or e-mail when the device is triggered by risky driving or if the vehicle is leaving a predefined geofenced area.

ZoomSafer (www.zoomsafer.com): Zoomsafer has a solution similar to the iZUP application, using GPS signals and speed. It includes Bluetooth technology to pair a user's cell phone with the car so the application will be automatically turned on when car ignition is on. It also includes enhanced features such as hands-free restriction (Bluetooth use only), e-mail or text message forwarding options, and voice recognition and voice reading of e-mails and text. Zoomsafer has multiple products that meet different needs for commercial enterprises, families, and individuals. The software runs only on BlackBerry smart phones.

2.3.3. Summary of technologies

A summary of these geofencing technologies is presented in Table 2-4.

Table 2-4 Summary of Geofencing Technologies

Technological Component(s)	Product/Service	Type of Service	Type of solution	SmartPhone Compatibility	Cost
Location-based Geofencing (GPS, WiFi, and Cell ID positioning)	PlaceCast	Commercial advertising geofencing	Software	Any	based on advertisement volume
	ShopKick	GeoFencing/Consumer Reward	Software	Iphone	free
	Zentracker	Geofencing/GPS tracking	Google Latitude (Software)	Any	free
Geofencing based on Cell phone GPS speed and Location	Cell Safety	Teenage / Fleet Monitoring Driving Distraction Prevention	Software	Blackberries, Android, Nokia S60 phones-	
	DriveAssist	Driving Distraction Prevention	Software (GPS and other sensors to detect speed)	Blackberry	N/A
	iZUP	Driving Distraction Prevention	Software (using GPS Speed)	android and blackberry	$5/month
	PhonEnforce	Driving Distraction Prevention	Software	Blackberries, Android, Windows	
	Teentracker	Teenage Monitoring	Software	Iphone	$4.99
	TxtBlocker	Driving Distraction Prevention	Software (using GPS Speed)	Blackerry, Iphone, Android, Palm Pre	$9.99/month +$24.99 activation fee
Geofencing technologies that use on-board device to prevent distracted driving	CellControl	Driving Distraction Prevention	Software and Hardware (use in-vehicle Bluetooth device to disable phone usage)	HTC, Motorola, Nokia, Pantech, Blackberry, and Samsung	24.95 for phone activation, $89.95 for device, and $107.40 for one year subscription
	Key2SafeDriving	Driving Distraction Prevention	Software and Hardware (Can use in-vehicle Bluetooth device to disable phone usage)	Blackberry, HTC, Nokia and Samsung	$99.95 for device and software
	OCK	Driving distraction prevention	Software + hardware in car (sensors installed in the car to detect car ignition, and disable phone usage)		
	Signal Safe	Driving distraction prevention	Hardware (device installed in the car to issue visual warning)	Compatible with all phones	

	SimpleTrack	Monitoring risky driving + distracted driving prevention	Hardware installed in the car		
	ZoomSafer	Driving Distraction Prevention	Software (using GPS signal and speed) and Bluetooth device in the car	Blackberry	depend on type of product (private or commercial use)

2.3.4. Conclusions

Various existing geofencing products and services that are marketed on the web have been reviewed to provide a brief overview of the geofencing function developed for the Networked Traveler Project.

Most of the geofencing products and services are developed for driver-oriented applications. The technologies behind these products are similar: they use a combination of geo-location, speed and/or Bluetooth communication devices to detect where the user is, whether the user is driving or not, and then take action based on that detection to block usage of the phone (either partially or fully) and in some cases, alert the user or parents.

It is noted that simple geofencing concepts (i.e., methods based on location and/or vehicle speed alone) are unsuitable for the Networked Traveler Project, which seeks to provide traveler information when used on transit vehicles, but does not allow use while driving. Therefore, when only a software solution is applied, none of the above listed commercial products fit the needs of Networked Traveler, since these technologies can only detect whether or not the phone is in motion, but not the mode (driving versus riding on transit). With only the GPS location and speed, reliable mode detection is very difficult. Knowing the real-time GPS information from all buses and trains, with the aid of user itinerary information, can help make the mode detection much more reliable. Therefore, the geofencing module needs to be an integrated part of the NT system such that GPS location for travelers and transit vehicles can be linked. This is the method currently employed in the Networked Traveler Project.

If additional hardware in the vehicle could be used to disable phone usage via Bluetooth communications or other devices that are connected in the car, then some commercially available geofencing technologies, such as those used by Key2SafeDriving and CellControl, would support NT geofencing.

2.4. Selection of Candidate Caltrain Parking Lots for Field Testing

According to the report "February 2008 Caltrain Annual Passenger Counts", the ratio of traditional peak commuters (northbound morning and southbound evening) to the reverse peak commuters is about 60/40. Fifty-six percent of northbound morning peak commuters have San Francisco as their destination. Focusing on the morning peak commute market, the following criteria were used for the selection of appropriate Caltrain parking lots for sensor instrumentation:

- The station has relative high passenger boarding numbers;
- The station has accessibility to Baby Bullet and/or limited trains;
- The station itself or at least some of its satellite stations have not fully utilized parking; and
- The station is graphically close to most frequent congestion areas on HW 101 for quick response in congestion relief.

The occupancy rate at all Caltrain parking lots and the layout of several interesting parking lots were surveyed. The surveys were conducted by PATH on September 24, and November 20, 2008. Figure 2-4 shows the average boarding numbers (northbound morning peak) together with the occupied and available parking spaces at all Caltrain parking lots, between the San Jose Diridon station and San Francisco.

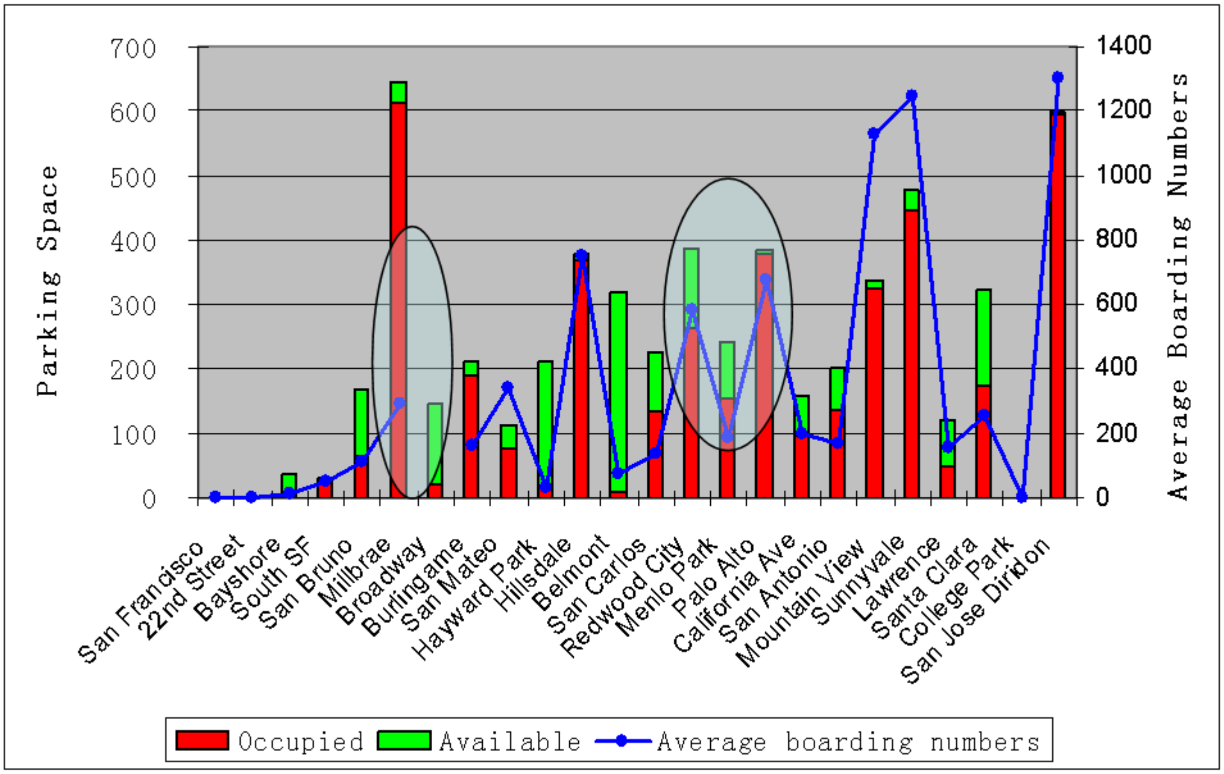


Figure 2-4 Parking lot occupancy and average boarding numbers (northbound morning peak)

The two shaded areas in Figure 2-4 are the two sets of stations for which we have instrumented parking lots. The first set (i.e., Palo Alto, Menlo Park and Redwood City) is the primary selected set and the second set (i.e., Millbrae).

Palo Alto and Redwood City (RWC) are two transit centers for their neighborhoods and they are ranked as the 5th and 6th stations, respectively with regard to the number of boardings in the northbound morning peak. Together with Menlo Park, these three stations account for 17% of all northbound morning peak commuters. All three of these stations have good accessibility to Baby Bullet/Express trains. In fact, Palo Alto is one of the only three stations that connect to all Baby Bullet trains (with the other two are San Jose Diridon and Millbrae). When Palo Alto parking lots are full, Menlo Park and RWC parking lots are available to drivers, given that parking information could be effectively delivered to commuters.

The Millbrae Caltrain/BART intermodal station is the primary transit hub in San Mateo County, the largest one west of the Mississippi River. It is close to one of the most frequently congested areas along US-101 (between SFO and San Francisco). Caltrain does not provide weekday service at Broadway, and that may be the reason why the occupancy rate at the Broadway parking lot is extremely low. Caltrain does provide non-stop free shuttle service between these two stations (5 minutes travel time). When Millbrae parking lots are fully occupied, travelers can be guided to park at Broadway, take the free shuttle, and make a transfer at Millbrae.

Table 2-5 below summarizes the characteristics of instrumented parking lots

Table 2-5 Instrumented Parking Lots

Site	Parking Space	Parking Lots	Average occupancy	Baby bullet / express train	Average Boarding Numbers (NB AM peak)	Connection
Palo Alto	385 376 standard 8 handicap	3 open lots (Instrumented West Lot)	98%	Baby bullet + express	674	Multiple VTA bus routes
Menlo Park	243	3 open lots (All imstrumented)	60%	Express	183	Multiple Samtrans bus routes
RWC	560	2 open lots + 1underground (Instrumented two of them)	65%	Baby bullet + express	584	Multiple Samtrans bus routes
Millbrae (second set)	645	one Caltrain exclusive and several shared with BART (Instrumented the exclusive Caltrain lot)	95%	Baby bullet + express	292	

Figure. C-3 through Figure. C-5 in Appendix C show the layout of the selected Caltrain stations for which we instrumented their parking lot(s). Please find additional details in Appendix C.

3. Integrated Multi-modal Traveler Information System Design - Path2go

3.1. System Requirements

The requirements of the Path2go system are derived from the research objectives. The first requirement is to provide multi-modal traveler information with trip planning. The year 2000 San Francisco Bay Area Census data obtained from the Metropolitan Transportation Commission (MTC) showed that both train and bus riders could be multi-modal users (Metropolitan Transportation Commission, 2000). It is obvious that provision of integrated multi-modal traveler information would have the most potential to affect traveler behavior (Kenyon & Lyons, 2003). Also pre-trip planning, compared to wayside or onboard information (Grotenhuis, Wiegmans, & Rietve, 2007), is considered the most effective stage when IMTI should be provided.

Provision of real-time transit arrival information is another requirement for the system. As shown in (Grotenhuis, Wiegmans, & Rietve, 2007), real-time transit information (which includes real-time delay info) is desired for the IMTI system by more than 90% of survey respondents.
Search efforts using the online planning and transit information tools can be effectively reduced by an online exploration tool that searches the ITMI by name, address, etc. Google ® Transit has very powerful point-of-interest exploration capabilities, which while not specifically designed for transit riders are still quite useful. OneBusAway, developed by the University of Washington, provides an easy-to-use search tool that allows users to find transit routes and stops by name or nearby address (Watkins & Ferris, 2010). Most other online tools only allow a step-by-step look up using transit agency, route and stop name. A search capability could be equally useful for frequent transit users who may need a quick update of the bus or train arrival time without having to enter an origin and destination to get trip plans.

On-the-go traveler information for wayside and onboard stages via mobile phones is another requirement of the Path2go tool. Mobile IMTI has been greatly facilitated by the development of smart phone platforms. These have proliferated: a search on the Apple iTunes ® store using the keyword "bus" gives hundreds of applications for public transit worldwide, among which Google Maps and 511 mobile are two well-known mobile tools. A similar search on Android ® Marketplace also yielded 400+ results (searched on 11/01/2010).

State-of-the-art IMTI systems have incorporated some or all of the features above, including multi-modal information, real-time bus or train arrival, online search capabilities for transit information and design for use on mobile platforms. With the many data sources, travel modes and applications, it is clear that the integration of the IMTI will be the way to enhance the overall system. Table 3-1 shows the integration that could be achieved for IMTI systems at two different levels of integration: (1) by data; and (2) by mode.
The Path2go tool aims to improve the integration of IMTI at both levels. In addition to the implementation of the integrated features as described in Table 3-1, we have also included the following experimental features in Path2go:

- Comparison of multi-modal trips at a glance. Based on the research in (Kenyon & Lyons, 2003), we have designed a way of comparing different modal trip options based on travel time, fare and emissions savings for driving, driving to transit, transit and biking modes (biking mode trip planning result is powered by the Google ® web service).

- Integrated mobile and web-based application. The online tools such as a web-based trip planner and mobile based applications are usually considered as two different platforms for IMTI. However, they can be further integrated to allow innovative features that travelers can benefit from, such as registering a trip planned on the website for later en route guidance using a cell phone.

Table 3-1 Integration of IMTI at different levels for public transportation

	Integration	Example Systems
Data integration	Multiple transit agencies	511, Google Transit, Goroo, PATH2Go
	Integration of real-time data with transit schedule	Goroo, PATH2Go
	Traffic	511, Google, NAVTEQ ® traffic.com
	Parking	511, PATH2Go
Modal integration	Multiple mode choices	Google (Transit, driving, walking, biking) PATH2Go (Transit, driving, driving to transit) Goroo (Transit, driving, driving to transit, walking, biking)
	Driving-then-transit mode	Goroo, PATH2Go
	Integrated traffic in trip planning	511, Google Maps, PATH2Go
	Integrated real-time parking in planning	PATH2Go

3.2. System Architecture

The NT-T/SP system itself also needs to accommodate a bigger general architecture, so that other tasks such as transit operation management, transit planning and transit maintenance management can also be integrated into a whole ITS system. Figure 3-1 is such a layered transit ITS architecture. The dynamic passenger information (DPI) system architecture described in this report (see Figure 3-3 and Figure 3-4) is designed based on this architecture.

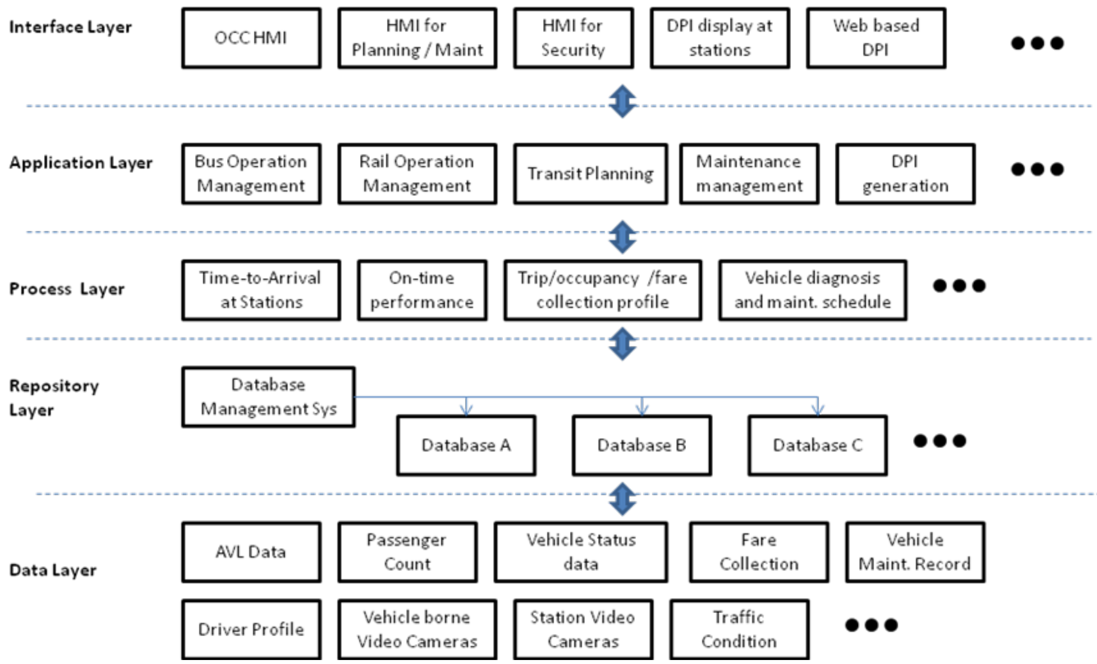


Figure 3-1 generalized transit ITS system architecture

3.2.1. System Components

The Path2go system is composed of the following typical components (Figure 3-2):

- AVL system which obtains transit vehicle's location, using GPS devices;
- Wireless communication system which provides two way linkages between a center and transit vehicles (buses or trains);
- Database system which archives static transit schedule and route information, real-time AVL data as well as the generated DPI information data;
- Bus-as-a-probe center that aggregates the AVL data from the buses and generates real-time arterial traffic information update. The real-time update is fed into the bus arrival time prediction, and can also be displayed at transit operation centers;
- Central processor which aggregates the data and generates estimated time to arrival (ETA) for the buses / trains, generates the DPI information for various information processes (for personal information, bus stop, etc.) and optimizes the routes for trip planning;
- Transit server that provides services for information in various formats and via different media.

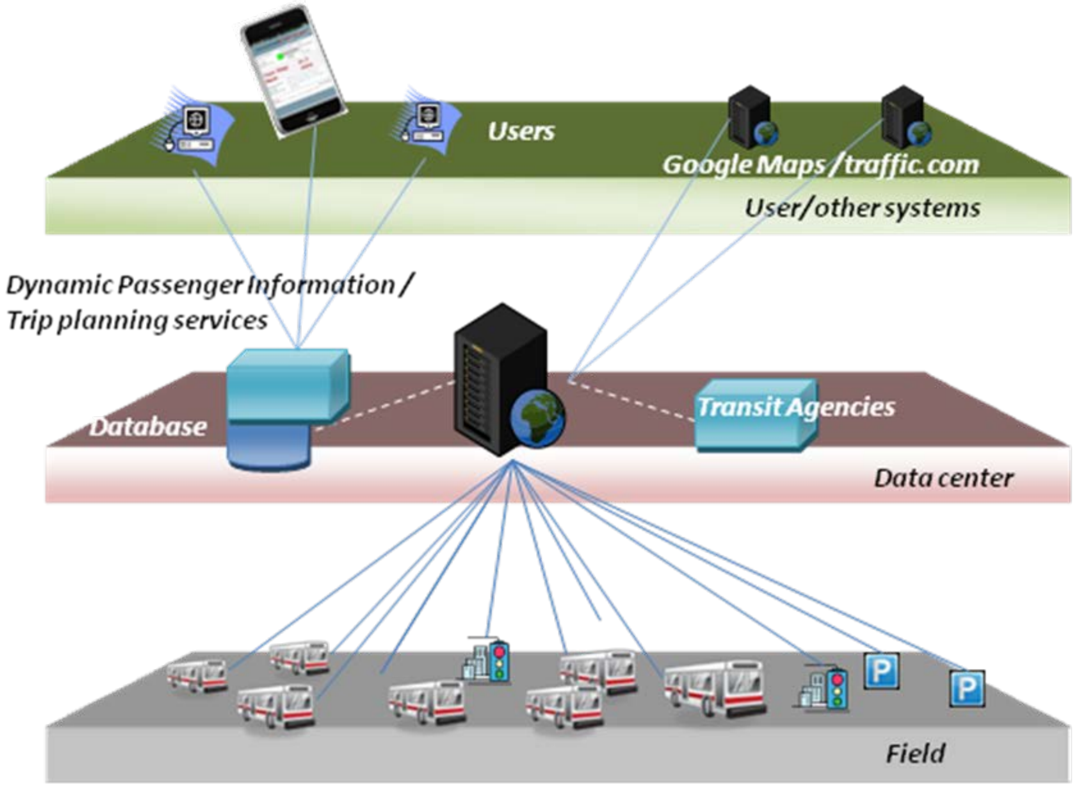


Figure 3-2 Connected Traveler Transit System Components

In summary, the system is designed to have a scalable architecture to meet different needs from existing systems of transit agencies. The design of the system architecture supports several different scenarios, is scalable, and takes advantage of existing AVL/ACS system as well as the existing real-time information system to provide a highly flexible solution for the DPI system (Figure 3-3).

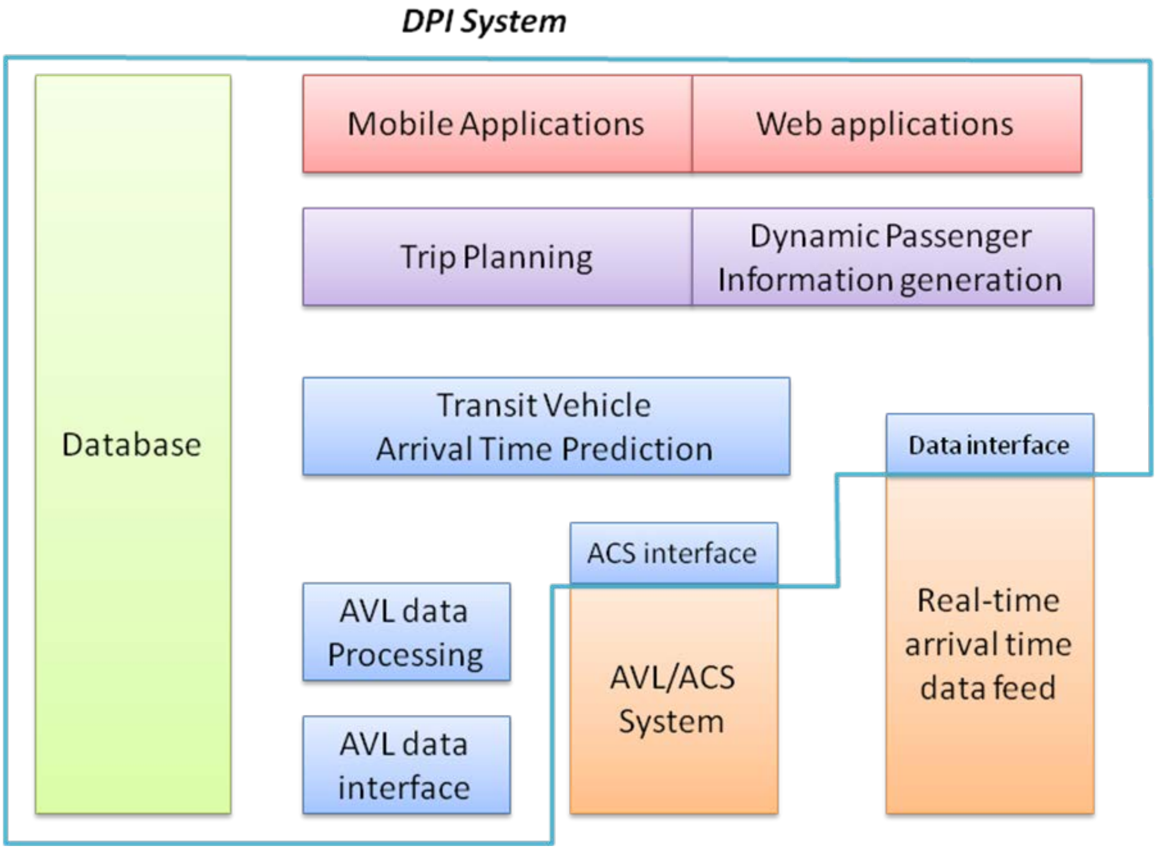


Figure 3-3 DPI System Architecture

The real-time arterial performance measurement system (APeMS) is a subsystem within the Path2go system. Figure 3-4 presents the functional architecture of APeMS. The central Path2go MySQL database stores the second-by-second BRT bus data together with signal status data. Once a probe bus is detected stopping at a bus stop, its travel time from the previous bus stop will go through three filtering programs to squeeze the bus stop effects, the cruise speed difference, and the signal waiting time. The residual time is bus queuing delay that is assumed to be the same as traffic queuing delay. The average arterial travel time is the queuing delay plus the free flow travel time and the average signal waiting time for other traffic.

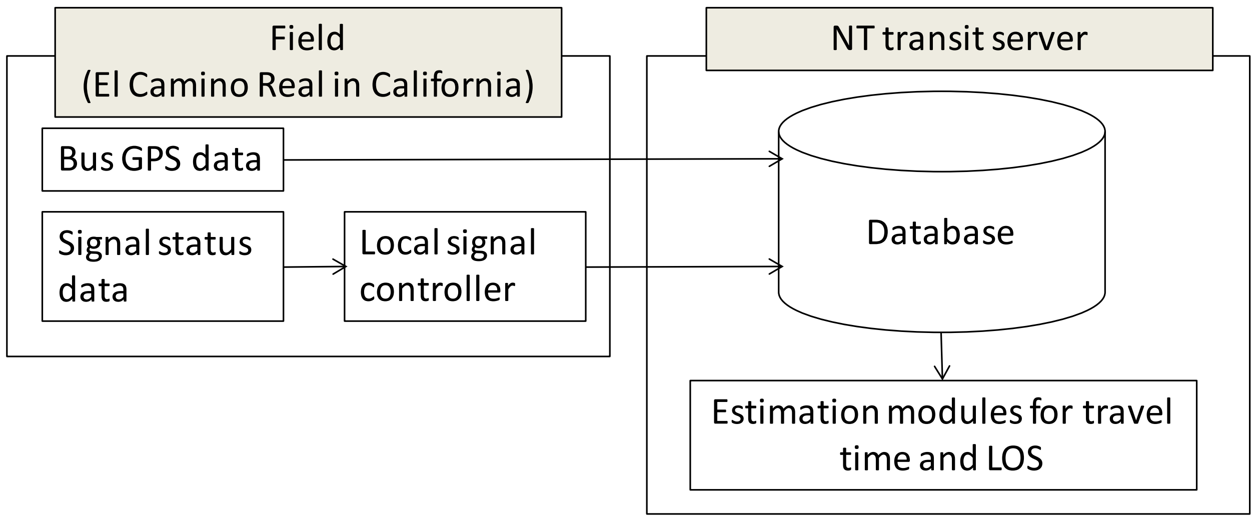


Figure 3-4 Architecture of real-time arterial performance measurement system (APeMS)

3.2.2. Path2go Server Modules

The Path2go server is comprised of the following modules:

- Multi-modal trip planning using real-time transit and traffic data. A web-based multi-modal trip planning tool that uses real-time transit arrivals, real-time traffic and parking information. Transit, driving to transit and driving are supported by the trip planner. The travel time of any mode involving driving is calculated based on real-time traffic data and historical statistics. Different trip options can be displayed in tabular form with comparison of total travel time, fare and emission savings to make it easier for the users to choose a preferred trip.
- A web-based transit information exploration tool. A web-based tool that supports searching real-time or scheduled information using either route name, stop name or a nearby address. User inputs are matched to the three different modes automatically using a best-effort match.
- En route information update. The objective of this application is to build highly accurate and timely en route information for the user based on their location and itinerary. The location of the user traveling via a multi-modal trip is tracked and projected to the itinerary. We developed a scenario-parsing algorithm to match the user GPS tracks with the multi-modal itinerary and GPS data from other sources (such as transit vehicles) to improve the situational awareness of the system. The information content generated for the users therefore becomes more personalized, accurate and timely. The location data from the mobile devices, however, are often seen to have poor quality due to bad reception in congested urban areas. The fact that multiple transit routes could share a single station means that multiple relevant transit vehicles may be associated with user location. We applied a multi-hypothesis data association approach in the matching of user location with trip segments and transit vehicles to deal with the uncertainty issue that resulted in more reliable matching. Results can be found in the section, "Fusion of Mobile Phone GPS from Users for Real-time Arrival Prediction". Information content is then generated for a certain user for any stage of a trip, either before the trip, driving to the train station, waiting at a bus

stop or while on a transit vehicle. Information includes the "update of your bus / train arrival time", "update of alighting time" when onboard the bus, alert of "approaching the destination stop", "low number of parking spaces" while driving to a train station.

Figure 3-5 shows the Path2go server components.

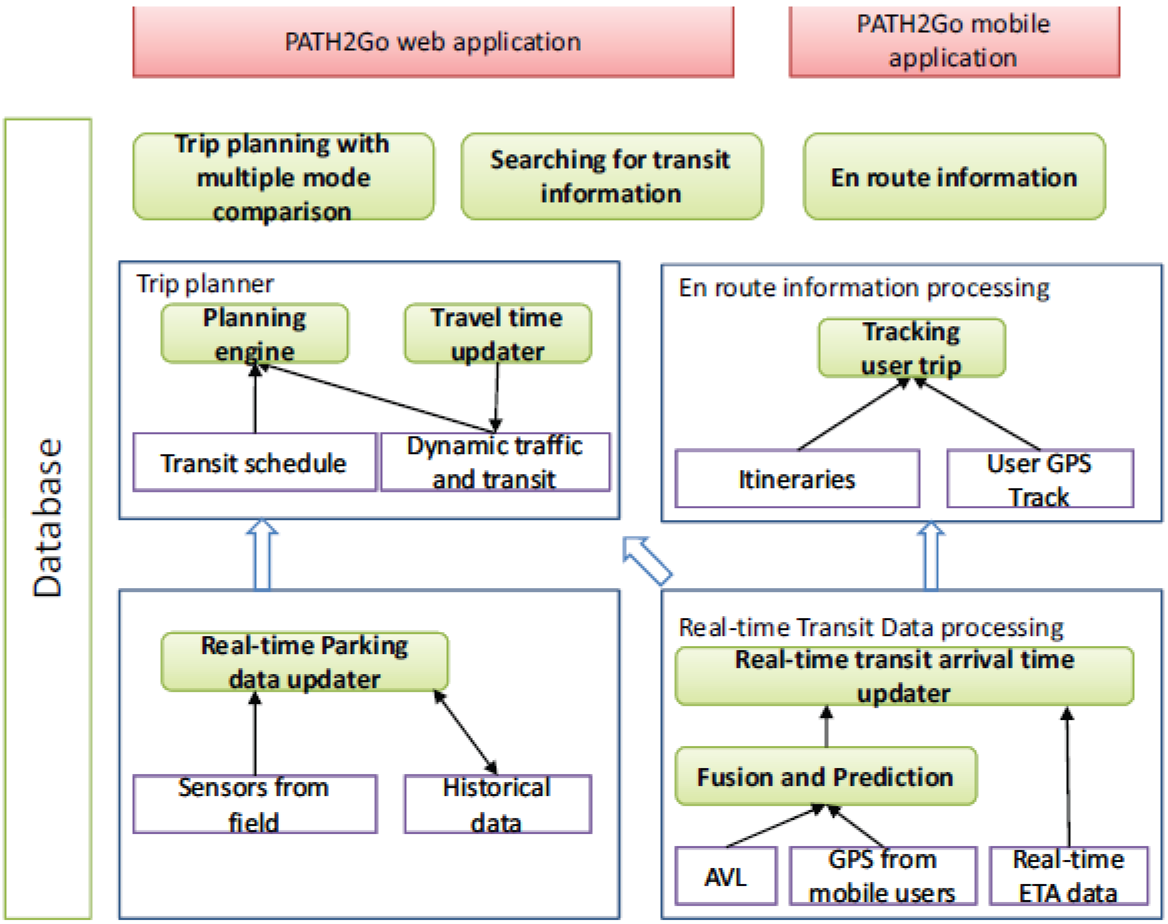


Figure 3-5 Path2go server components

Path2go is currently online at http://tlab.path.berkeley.edu/ (10).

4. System Implementation and Enabling Technologies

Path2go aims to provide a set of tools that can make transit information along the US-101 corridor more easily accessible to both existing riders as well as infrequent users. The approach adopted for Path2go and described in the previous section is to build an integrated system that makes the real-time IMTI easier to access at all stages of travel. Path2go applications are shown in Figure 4-1.

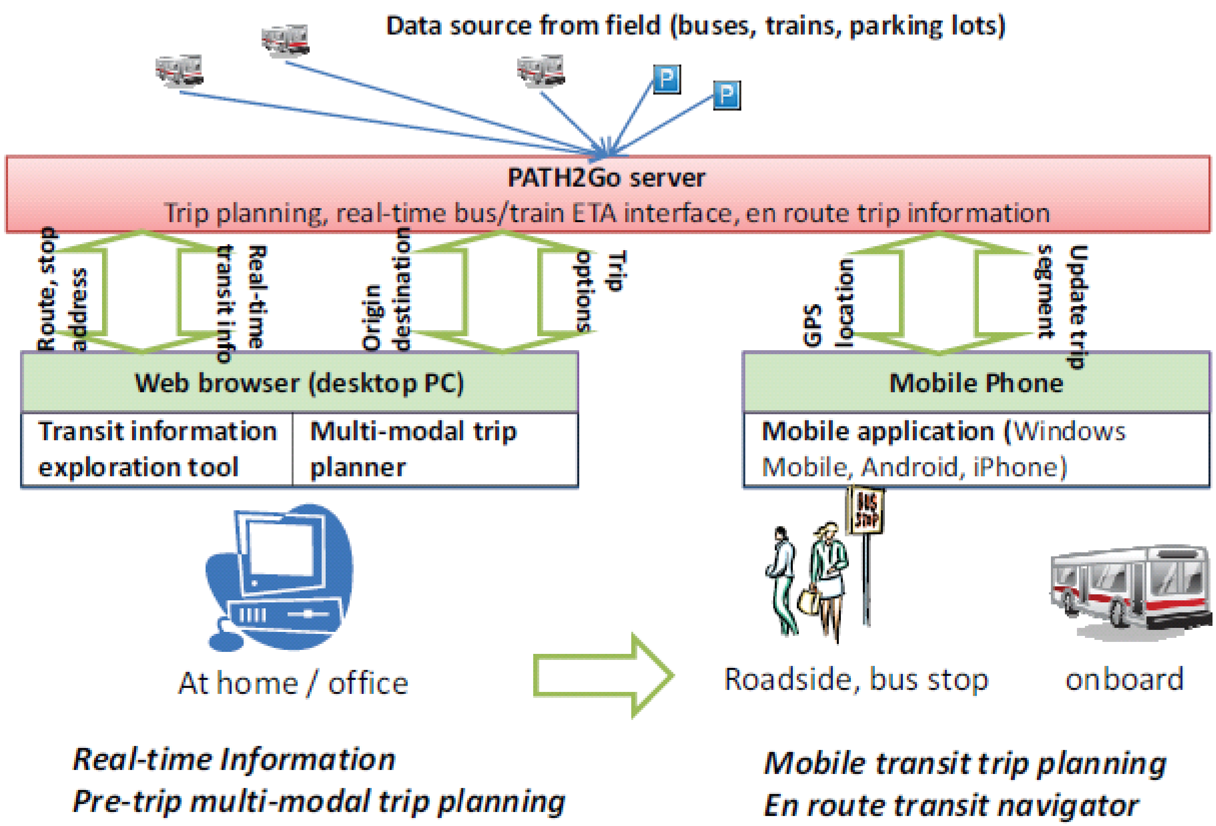


Figure 4-1 Path2go applications

4.1. Pre-trip Multimodal Trip Planning

The trip planner inherently implements the planning function along the US-101 corridor for driving, transit, driving to transit and walking as a necessary mode to make transfers. Users can choose either to compare all those modes, or plan a transit-only trip with the web interface. A dynamic multi-modal transit and traffic network is implemented as part of the trip planning engine. A dedicated thread on the server updates the network using real-time transit arrival information and real-time traffic data periodically. More details can be found in (Li, Zhou, Zhang, & Zhang, 2010). As illustrated in Figure 4-2, the planner provides an all-modes-at-a-glance feature that allows a direct comparison of travel time, fare and emission savings.

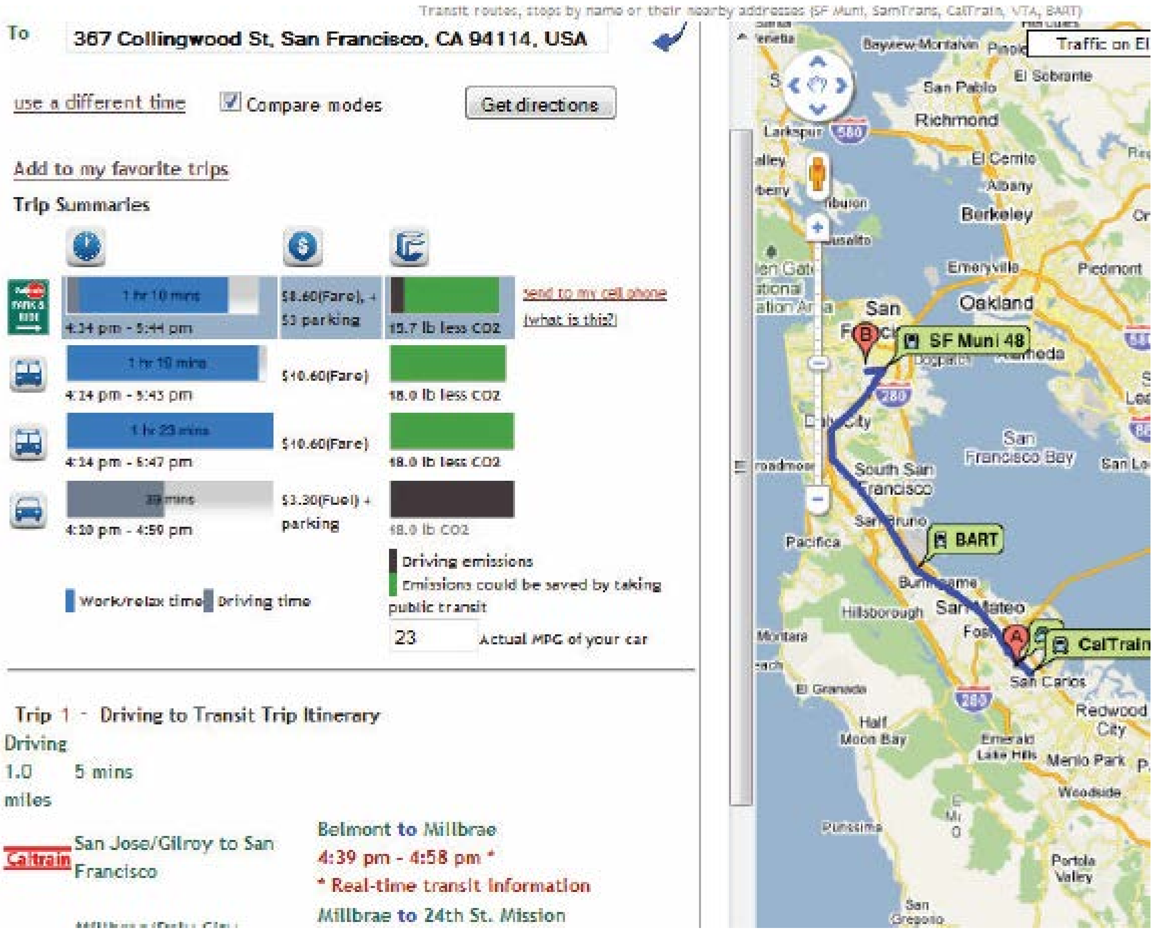


Figure 4-2 Multi-modal trip planner

4.1.1. Comparing Multiple Trips at a Glance

A. Travel time comparison

The total travel time for each mode is decomposed into two portions: the time spent on transit or waiting for transit versus the time spent on driving, whenever applicable. We differentiate the two different kinds of times spent on the trip to highlight the fact that time spent on transit could be used for working or relaxing, which in general is more productive and less stressful than driving. As pointed out in (Grotenhuis, Wiegmans, & Rietve, 2007), both time savings and the saving of effort are most valued by travelers. Since usually travel time by transit is not competitive with driving, highlighting the effort saved could potentially encourage consideration by travelers to take transit.

- Color coding: In our design, blue is used to indicate "working/relax" time and gray is used for "driving" time.
- Overall transit time or time of driving to transit includes driving time to transit stops (when applicable), walking and waiting time at transfer stops, time on bus or train and any walking time needed to get to the destination.

B. Cost Comparison

We have used the average fuel cost as the cost of driving. This is different from the way used by Google ® Maps and other applications where driving cost is calculated based on the average rate that an employee can get reimbursed. This "reimbursement rate" is considered to be an overestimate of the cost because it also includes insurance and depreciation of the car value, which occurs anyway even if the traveler shifts from driving to transit (Kenyon & Lyons, 2003). Therefore using the fuel cost only for driving will result in a more credible result when driving is compared to transit. We use the average fuel efficiency value of a passenger car in the U.S. (22.5 average miles per gallon (mpg), 2007 data (Research and Innovative Technology Administration (RITA), Bureau of Transportation Statistics)) to calculate the driving cost.

$$\text{Driving Cost} = \text{Mileage}=22:5(\text{mpg}) \quad (\text{gas price}): \tag{1}$$

C. Emission Savings

Emission (savings) is another major benefit of taking transit in addition to the potentially more productive time on transit when compared to driving. Emissions are measured using the amount of CO2 in pounds.

In the calculation of emissions savings we are not using the difference of driving versus transit. The calculation is based on the following assumptions:

- For driving mode, we assume that there is only one vehicle occupant (the driver);
- If the traveler takes transit, then there will be an additional passenger on the bus; and
- Since the bus runs anyway on the route regardless of how many passengers on board, the basis of calculating the emission difference is the car emissions less the additional emissions caused by one more passenger on bus, rather than the actual emissions of the bus. We denote the emissions of a bus $E(N)$ as a function of the number of passengers on bus (denoted as N), and use the additional emissions E defined as

$$\Delta E = E(\text{N} + 1) - E(N), \tag{2}$$

in later calculations.

- Emissions for driving

$$\text{Emissions Driving} = 19.4 * \text{Mileage/mpg}, \tag{3}$$

where 19.4 is the average CO2 emissions per gallon gas measured in pounds (EPA, 2005) and mpg is the actual miles per gallon of the user's personal vehicle that is provided by the user with the default value set to 22.5 mpg (Research and Innovative Technology Administration (RITA), Bureau of Transportation Statistics).

- Emission savings for transit

$$\text{Emissions saving} = \text{Emissions Driving} - \Delta E, \tag{4}$$

where "ΔE" is the additional amount of emissions caused by one more passenger on the bus (or train) as defined in Eq. 2.

E is calculated in the following way. First we use the experimental results of the emissions of heavy-duty buses as a function of their load (c.f. (Lyons, 2008.)). The results showed that emissions of fully loaded buses were increased by less than 10% when compared to being empty loaded. The added weight when fully loaded was approximately 9000~10000 lbs.

Therefore the additional emissions caused by a 200-pound passenger would be less than 0.2% of the bus emissions, assuming that the extra amount of emissions caused by passengers is a linear function of the load). So ΔE can be approximated as

$$\Delta E = 0.2\% E_D \text{ miles} \tag{5}$$

where E_D is the average CO2 emissions per mile of a heavy duty bus. We use the average value (4.85 lbs /mile) over the results from three test fleets as reported in (Lyons, 2008.).

4.1.2. Design of a Trip Planning Algorithm for Real-Time Traffic and Transit

Figure 4-3 presents the architecture of the trip planning server. While the essence of most multi-modal trip planners is to seek good travel routes for given origin, destination and starting/arrival time, finding good routes is far more complicated than solving a simple shortest path problem. First, different users may have different preferences. For example, some users prefer trains to buses. It is also difficult to model these preferences using some quantitative weights. Assume that there are two routes, where one route requires a slightly longer walking distance, while the other one requires a slightly longer time staying in the bus. Different users may have different opinions on which route is better. Therefore, multi-modal planners generally provide several good routes to users so that the users can choose the best one from these routes by themselves.

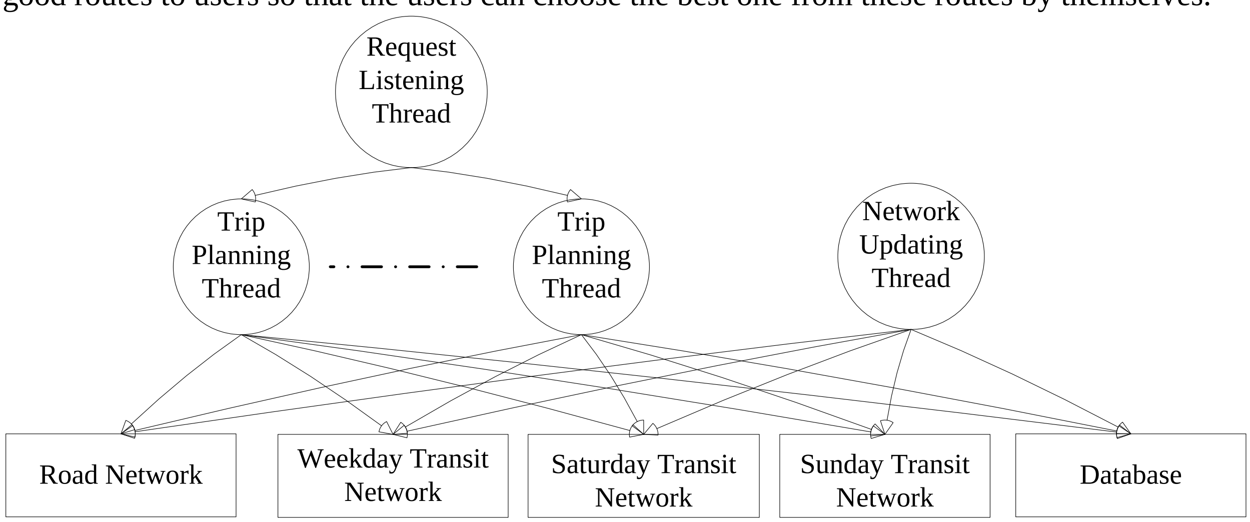


Figure 4-3 The architecture of the trip planning server

4.2. Details about the trip planning server and algorithms can be seen in Appendix D. Predictive Bus / Train Arrival Time Using AVL Data

The generation of the predictive bus /train arrival time usually involves several data processing procedures, including the identification of the route and direction that a bus/train is running on, the map matching and schedule matching and then a prediction of the arrival time based on GPS locations and historical data. Data from different agencies vary a lot, not just in their formats, but also in the availability of certain information and their quality as well. Due to the lack of the real-time data for certain critical routes for the project, we also had to instrument buses and locomotives.

To summarize, we have the following different kinds of real-time data sources:

Table 4-1 Different data sources

Agency	Data	Format	Description
SamTrans	Static schedule	511 XML format	Transit route description, time point file, service days and schedule at time points
	Real-time AVL data	plain text	Vehicle ID, GPS location, speed, block #, running route and direction, time point offset.
VTA BRT	Static schedule	GTFS (Google transit feed specification)[1]	Including every aspect of the transit static data.
	Real-time AVL	NMEA GPRMC [2] (second by second GPS only)	Instrumented by PATH (19 buses instrumented) Vehicle id, GPS location, speed and serving route.
AC Transit	Static Schedule	511 XML	Same as Samtrans
	Real-time AVL data	Plain text	Vehicle ID, GPS location, speed and block #.
Caltrain	Static Schedule	GTFS	
	Real-time AVL data	NMEA GPRMC (second by second GPS only)	Instrumented by PATH (29 locomotives instrumented)
SF Muni	Static Schedule	Public Data feed in XML	Provided by SF Muni , publically accessible.

[1] Google transit feed specification has been widely adopted as format for exchange of static transit schedule information http://code.google.com/transit/spec/transit_feed_specification.html

[2] NEMA National Marine Electronics Association (NMEA) has developed a specification that defines the interface between various pieces of marine electronic equipment. GPRMC is a standard sentence format for GPS data exchange. http://www.gpsinformation.org/dale/nmea.htm

	Real-time AVL data	XML data feed	Provided by SF Muni, publically accessible.
BART	Static Schedule	Public Data feed in XML	Provided by BART, publically accessible.
	Real-time AVL	Public Data feed in XML	Provided by BART, publically accessible. (Limitation: Data does not contain running route information)

Path2go aggregates the data from all different agencies and integrate into one central database with unified architecture and design so that predictive arrival times for all agencies can be generated and provided to the user in a unified interface.

There have been a few passenger information systems deployed (or to be deployed) in the San Francisco Bay area, including by SamTrans and VTA with both SamTrans and VTA having deployed advanced communication systems (ACS) on their bus fleets. The ACS is utilized to track the location of each bus. Each bus is equipped with a GPS receiver that allows the on-board Advanced Mobile Data Terminal (AMDT) to determine its current real-time location and schedule adherence. This information is transmitted via Ultra High Frequency (UHF) radio through repeater sites to ACS servers at an Operations Control Center (OCC). The ACS server polls each bus approximately every 1 to 2 minutes for its location status. The AMDT also provides two-way text messaging capability between the bus and the OCC. The AMDT has a small liquid crystal screen used to display simple text messages (such as bus detours or service interruptions) in addition to time and schedule information for the bus driver. In 2009, SamTrans started its dynamic passenger information (DPI) project, which by using the ACS system provides real-time bus arrivals at the bus stops.

Path2go explores the possibility of better transit service beyond what the current ACS/DPI system can provide by (1) better data quality with the ubiquitous wireless wideband connectivity which enables much higher frequency in the AVL data update; and more important based on the more frequent AVL data and a more reliable predictive bus arrival time which is generated with full understanding of the transit routes, the real-time bus location, the arterial traffic and the signalized intersection delays; and (2) personalized passenger information that is pushed to the smart phones to the travelers based on the itinerary. The NT transit server generates the information of “your bus”, “your train” and “your stop” in addition to the traditional transit information that is only for a certain station.

The generation of high quality real-time transit information involves the following important efforts: (1) understanding the transit operation for better arrival time predictionand an advanced algorithm to reliably predict bus arrival under complicated arterial traffic conditions.

PATH project team members have acquired significant knowledge of transit operations from previous transit signal priority and passenger information projects, and have developed a reliable algorithm that works for AVL data with variable updating frequency and accuracy. The next two subsections will briefly review the technologies used in Path2go for the generation of predictive arrival time.

4.2.1. Understanding the transit operation

There are two types of transit stops (bus stops or train stations): stops and time-points. The difference between them is that, at time-points, a transit vehicle can arrive before - but not leave earlier than (so called time-point holding) - the stated time as indicated in the route schedule.

Table 4-2 below lists the number of stops, number of time-points and route length for the 4 above referenced transit routes. Most of Caltrain's rail services are operating between San Francisco and San Jose, therefore the information for Caltrain is provided both from- and to-Gilroy and San Jose. As a BRT line, VTA Rapid 522 has many fewer stops, compared with normal transit routes.

Table 4-2 Transit Stops and Time-Points

Transit Route	Length (miles)	Direction	Origin	Destination	Total No. of Transit Stops	No. of Time-Points
VTA 522	25.8	WB	Eastridge T.C.	Palo Alto T.C.	30	13
		EB	Palo Alto T.C.	Eastridge T.C.	30	13
Caltrain	77.2 (47.5)	NB	Gilroy (San Jose)	San Francisco	31 (25)	31 (25)
		SB	San Francisco	Gilroy (San Jose)	31 (25)	31 (25)

Transit agencies operate multiple services along a one-way transit route, with different origin-destination (O-D) pairs. For example, the origin point for weekday Caltrain northbound trips can start at Gilroy Station, Tamien Station and San Jose Diridon Station.

SamTrans routes 390 and 391 and Caltrain provide schedule-based transit services, where the point-holding discipline is applied. Although VTA has a published schedule for Rapid 522, Rapid 522 buses will travel as fast as traffic and signals allow, meaning that buses will not sit idle at time-points when ahead of their route schedule. Therefore, Rapid 522 is more like a headway-based service.

Buses share the roadways with general traffic. In the design of a route schedule, the expected route travel time (for example, the 85-percentile traffic travel time) is combined with the slack time, and leads to schedule stability. If the slack time is insufficient, transit vehicles are unlikely to catch the schedule when falling behind, thereby downgrading the service reliability. On the other hand, large slack times reduce service frequency and increases transit waiting times and travel times.

Figure 4-4 clearly shows that route schedules match the traffic patterns. The scheduled travel time is smaller in the early morning and evening, when traffic is lighter, and is larger during the rush hours.

Caltrains' rail service, although also following the time-point discipline, is different than bus service as trains do not share roadway with traffic, thus schedules have little correlation with traffic patterns. Figure 4-6 below shows the scheduled travel times between San Jose Diridon Station and San Francisco Station for northbound and southbound Baby Bullet trains, which are consistently at about 60 minutes.

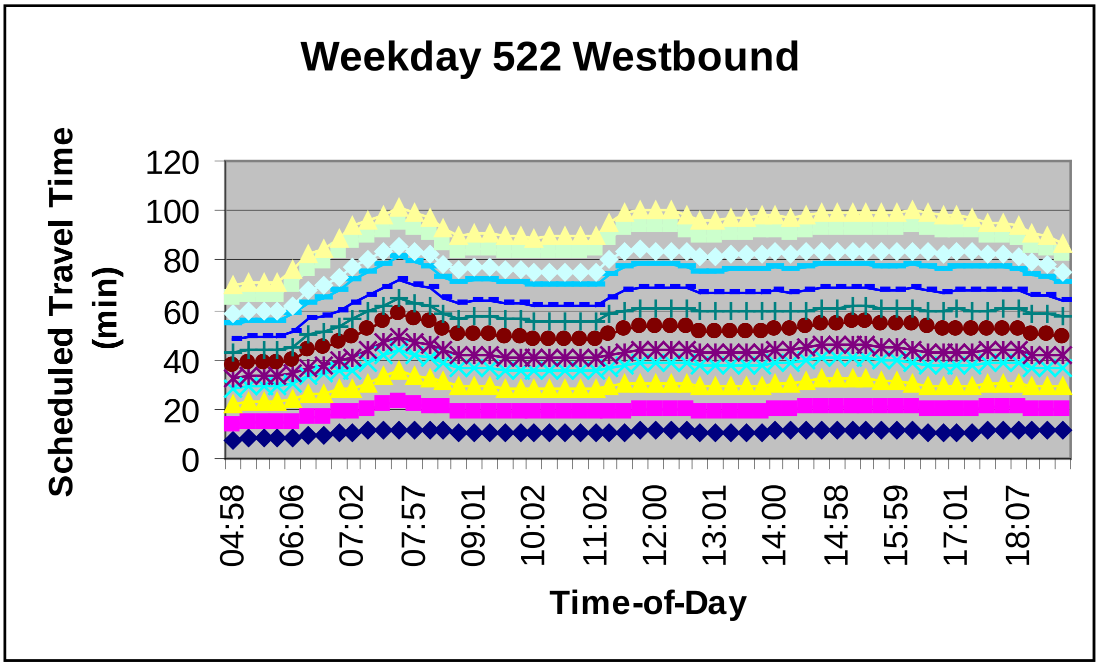


Figure 4-4 Scheduled Travel Time to Time-Points

(VTA Rapid 522 WB Weekday Trips)

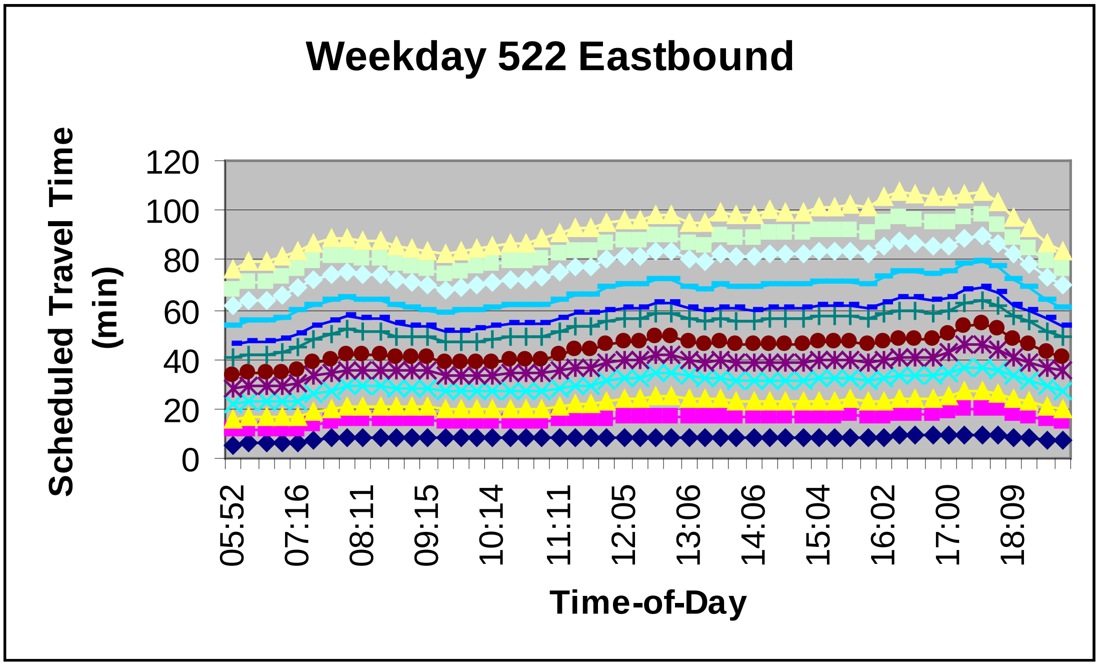


Figure 4-5 Scheduled Travel Time to Time-Points

(VTA Rapid 522 EB Weekday Trips)

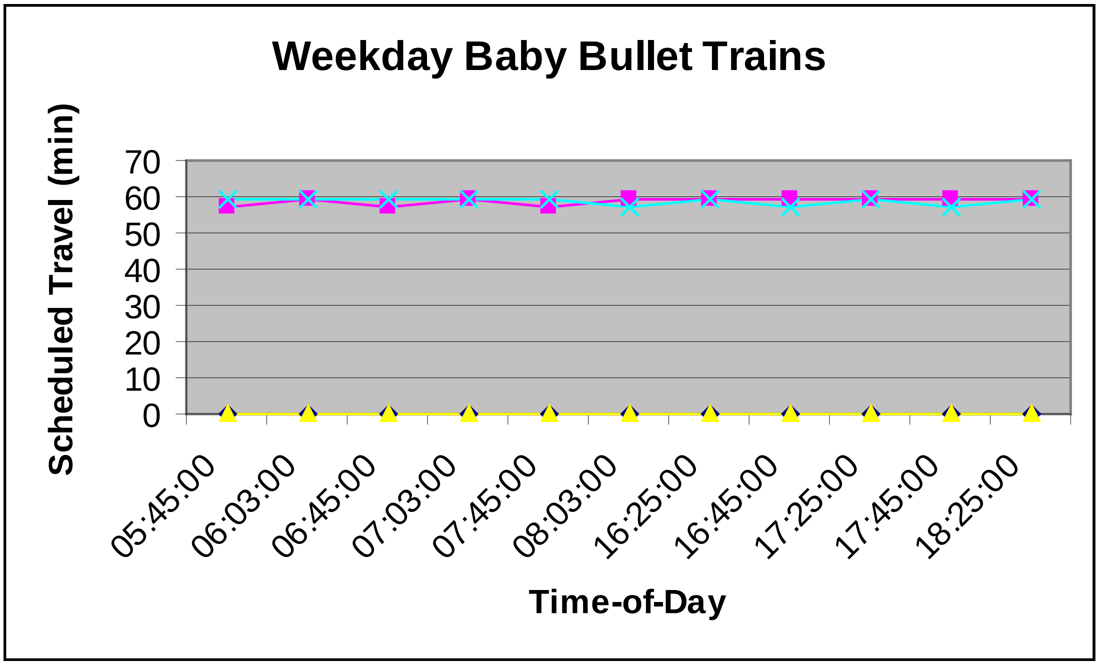


Figure 4-6 Scheduled Travel Time between San Jose and San Francisco

(Caltrain Weekday Baby Bullet Train Trips: -x- southbound, -■- northbound)

When utilizing AVL for dynamic passenger information features, the impacts of the AVL polling rate (between 1 to 2 minutes) need assessment. Actually when the AVL polling rate is low (such as 1-2 minutes polling as in the current ACS system) there is a crucial problem in providing travelers accurate transit information. Before receiving the next bus location update, the system may indicate the bus is approaching or waiting at a stop, while in fact the bus has already left the stop.

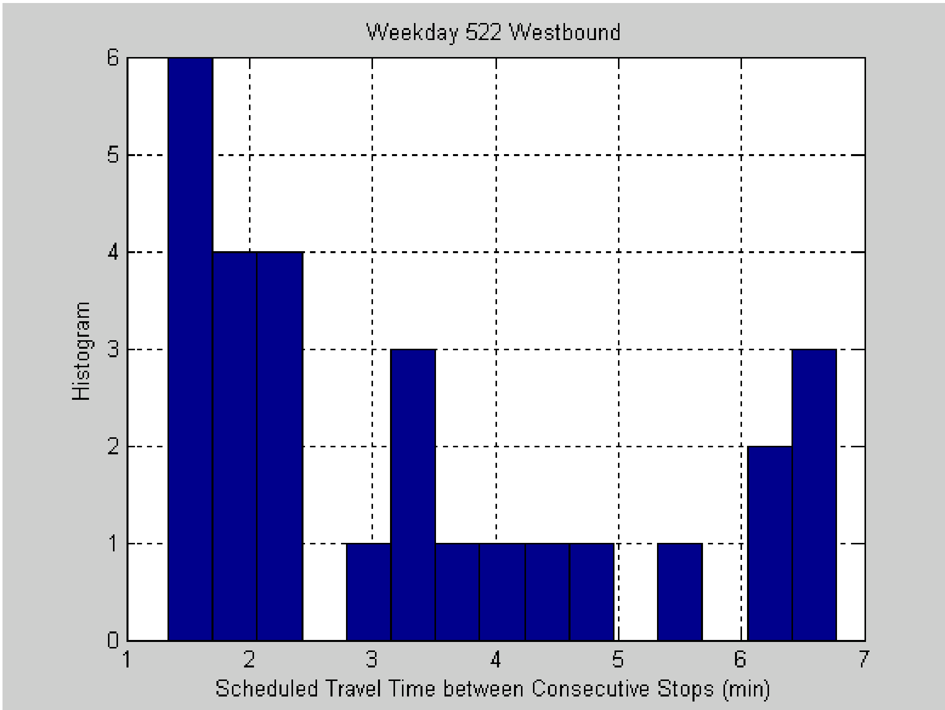


Figure 4-7 Scheduled Travel Time between Consecutive Stops

(VTA Rapid 522 WB Weekday Trips)

In summary, we have the following conclusions:

- Delivering dynamic passenger information to riders via their cell phone imposes a critical requirement for the accuracy of the predictive arrival time information, which in turn requires the AVL sampling rate to be high enough that the current approaching stop of the bus / train can be timely captured;
- Understanding the schedule pattern and the time-point adherence performance is critical for better bus arrival time prediction;
- Traffic conditions have impact on the travel time of the bus travel time. Therefore integration with the traffic prediction tool would help to further improve the prediction accuracy.

4.2.2. Reliable Prediction of Bus / Train Arrival Time

A typical transit trip involves travelers waiting at stop (bus) or station (rail) for the next transit vehicle, moving to a new stop/station, transferring to another transit vehicle or/and walking to the destination. Transit travelers' perceptions and satisfaction of waits, transfers and transit travel times contribute greatly to their decisions whether or not to take transit in the future.

Accurate prediction of the expected arrival time at individual downstream stops/stations is of significant value to both transit operators and travelers. There are a wide range of uncertainties in predicting bus travel time/arrival time, including the uncertainties in traffic condition, passenger boarding and alighting activities, and errors in transit vehicle positioning, among others. Some algorithms based on the Kalman filter have been proposed to predict the bus arrival time (Shalaby & Farhan, 2004).

To develop a reliable prediction algorithm, we collected bus operations data, examined operation characteristics, and assessed how real-time prediction can reduce the uncertainties in bus arrival times.

We use SamTrans route 390 as an example to illustrate the performance of the prediction algorithm. Route 390 is one of the most heavily used bus routes operated by SamTrans. It provides schedule-based bus services between the Palo Alto Transit Center and Daly City BART along California State Highway 82 - El Camino Real. The route is about 27 miles long, with 2-hour schedule travel time for most times of the day. It connects 6 CalTrain stations between Palo Alto and Hillsdale and 3 BART stations at Millbrae, South San Francisco and Daly City. Route 390 has 97 bus stops on northbound direction and 100 stops on the southbound direction. Of those, 11 are time points, where SamTrans has posted its schedule. The connection points to CalTrain and BART stations are all time points.

Portable GPS/GPRS devices were installed on 15 SamTrans buses to collect second-by-second bus movement data. The collected data were then processed to be projected onto the route, matched with schedule runs, and grouped in terms of run numbers. Some interesting characteristics of the bus trajectories were found by examining historical data collected from the buses. A strong correlation was found between the schedule deviation at downstream time points with the schedule deviation at the last time point and the dwelling time at the time point is not correlated with the experienced delay. Bus arrival time patterns at time-point stops were also found to have a so-called time-point holding phenomenon. Inspired by these findings, we developed a regression model in dynamical estimation of bus arrival and departure time which resulted in improved prediction reliability.

The performance of this model is shown in Figure 4-8. As a comparison, Figure 4-8 also shows the performance of using schedule as the basis for the estimation. Please find more details of this case study in Appendix E.

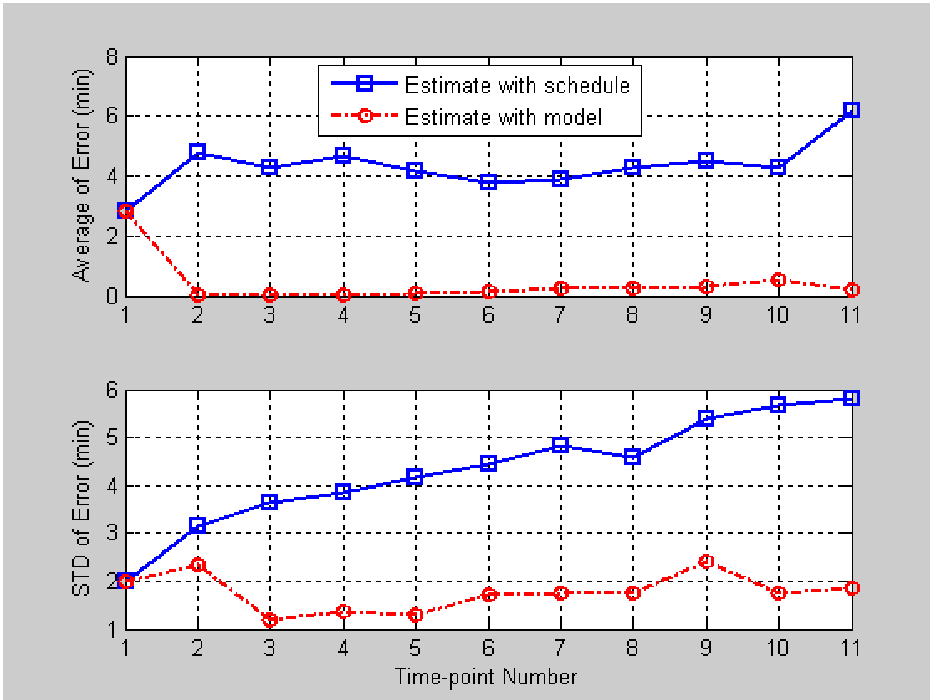


Figure 4-8 Performance comparison

We note here that this case study serves as an example to demonstrate that real-time estimation of a transit vehicle's arrival and departure time can significantly reduce planning inaccuracy. There is no "one size fits all" solution for different types of transit operation modes, e.g., scheduled-based versus headway-based, bus versus rail, fixed-route versus demand-responsive transit, as the operating environments and characteristics are very different.

4.3. Real-Time Transit Information

4.3.1. Presentation of the real-time transit information using web interface

Path2go provides a web-based user interface, which allows the user to do a "keyword" search of real-time transit information. The search text is processed to extract the following information:

- transit agency name,
- route name , partially or in full,
- name of transit station, or
- address of nearby stops that should be displayed, or
- search starts a trip planning when text pattern "A to B" is found.

To minimize the user's efforts in entering the information, a keyword can be entered freely with different combinations of the listed items in any order. A dynamic programming algorithm is implemented on the server to match user input with the listed items.

Figure 4-9 shows the user interface for the presentation of real-time transit information. We note that in this example, only the next CalTrain locomotive to San Francisco is real-time (since it has already left the starting station). GPS locations of the locomotives are also shown on the map.

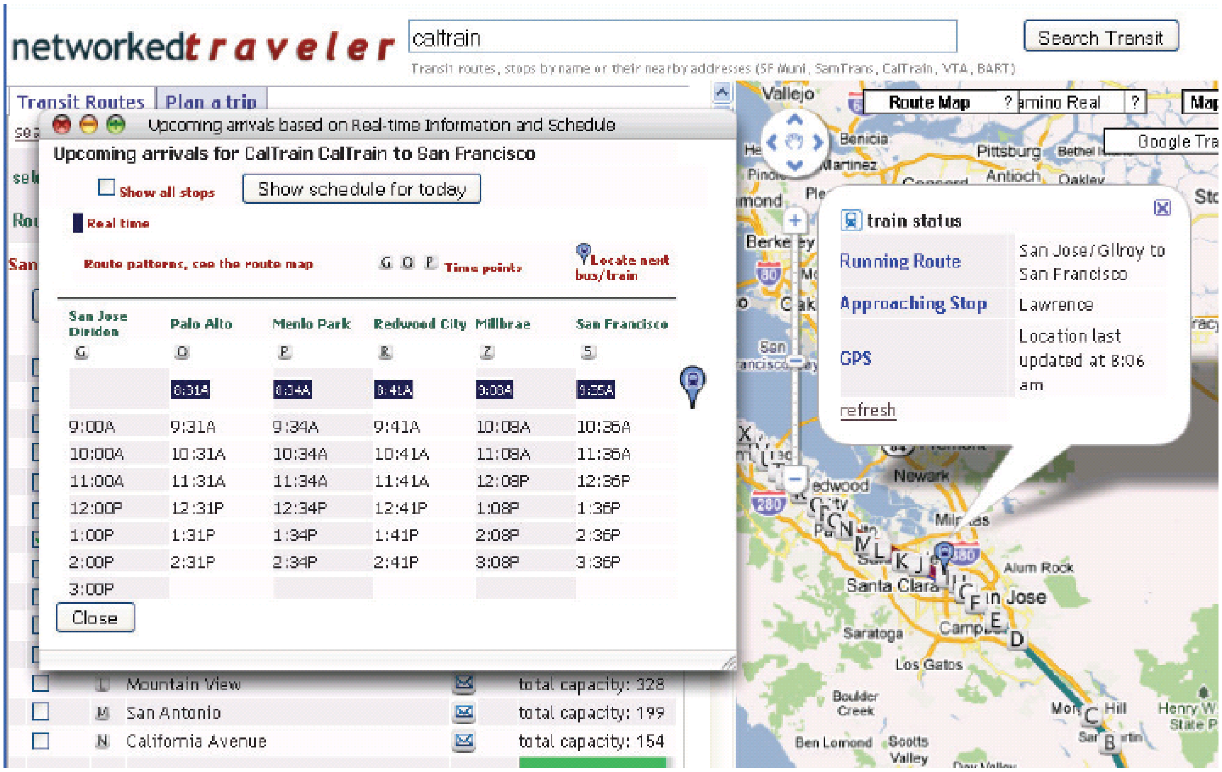


Figure 4-9 Presentation of real-time transit information

4.3.2. Generation of en-route real-time transit information

Providing simple and relevant real-time transit related information to the travelers in a timely manner is a challenging task. To understand the traveler's situation in the context of a multi-modal trip is one critical element of the system.

The timeliness and perceived usefulness of en route information relies on the level of situational awareness by the system. One possible way is to identify the traveler's situation by matching the location traces to his/her itinerary. This, however is a difficult task due to the complexity of traffic movement, low resolution of location data and the ambiguity caused by the combination of transit, driving and pedestrian traffic on the road.

Based on the GPS fusion algorithm, we built a reliable method to identify the mode and situation of the traveler via their GPS data, itinerary and AVL GPS traces from the buses and trains. The activity recognition algorithm is an iterative procedure that is applied to each user with a multilayer matching algorithm.

A. Map matching

With map matching, the "mapped location" helps to identify the "link" on the road, or "transit route". We note that since cars and buses usually share the same road, the mapped location would not identify the mode by itself. Since the rail network could very well be separated from the road network it could therefore be identified using GPS location only.

B. Activity identification

We divide the activities into "driving", "bus (onboard)", "rail (onboard)", "walking (transferring)", "at station", and "n/a". We note the activity as M, and the likelihood function of M as

$$L_M^t = \quad L_M\left(\mathrm{G}_u(t), L_M(t-1), \text{road network}, \right. \\ \left. \{d_{u,j} \text{for each transit vehicle j}\}, P_M\left(\mathrm{G}_u(t)\right)\right), \tag{6}$$

which is a function of the user GPS trace $G_u(t)$, the previous identification result L_M (t−1), road network information, empirical probability of the user GPS trace belonging to an activity M (the probability of which is P_M ($G_u(t)$)) and the fusion result with the transit vehicles. A state machine needs to be maintained for each user to iteratively update the activity identification results. Due to ambiguities and GPS errors, multiple hypotheses also need to be kept and iteratively evaluated using the multi-hypothesis association algorithm. The output is the hypothesis with the highest likelihood. The recognition algorithm is implemented as a Markov Chain model with each hypothesis independently tracked as a Markov Chain (18). The state-machine model is illustrated in Figure 4-10.

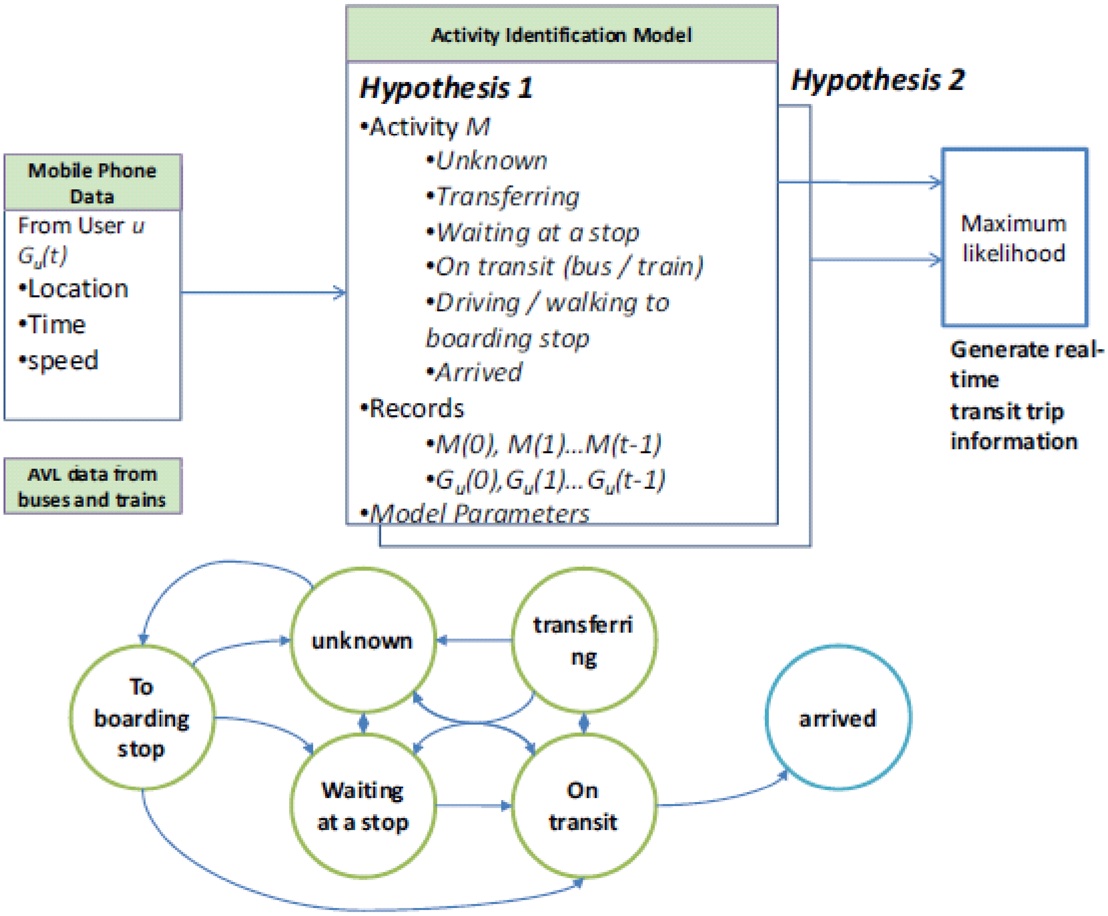


Figure 4-10 Activity identification model

System testing result of 116 trips showed that the correct identification rate of the user activity by the server was approximately 95%, which accounts for 110 of the 116 trips.

C. Generate information

Based on the identified activity of the user obtained from layer 2, the system can further generate information for specific scenarios such as "waiting at a certain bus stop", "walking towards train station platform", "parking the car at a train station", or "driving towards a train station", etc.

Figure 4-11, Figure 4-12 and Figure 4-13 are sample screenshots of the mobile user interface. Figure 4-14 also shows a successful matching of the user GPS trajectory and the AVL GPS trajectory from the train that the user was onboard. The GPS on the user cell phone was then turned off to save battery power.

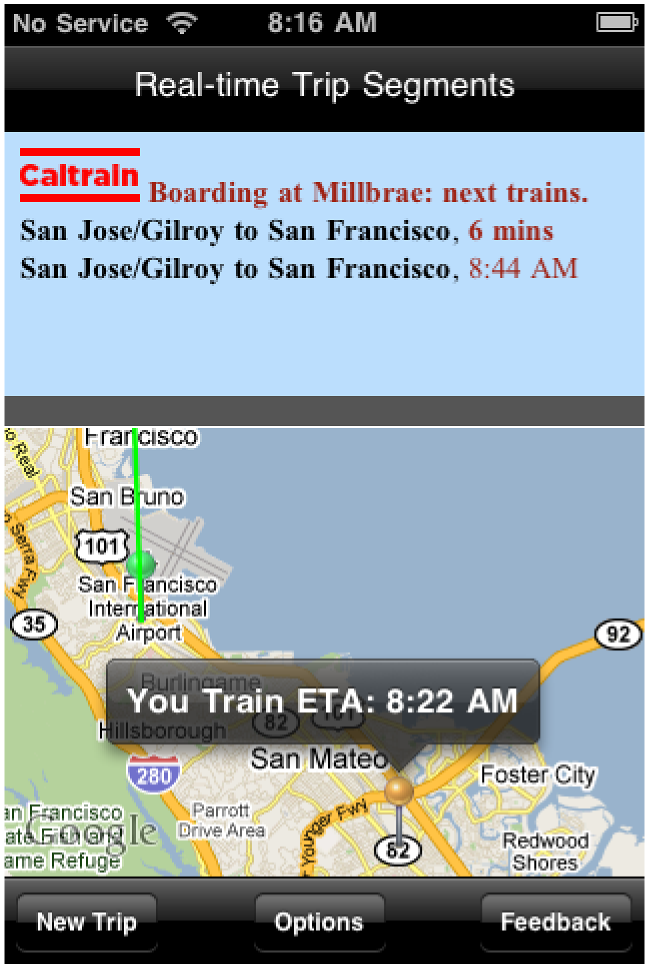


Figure 4-11 Mobile user interface (pre-trip)

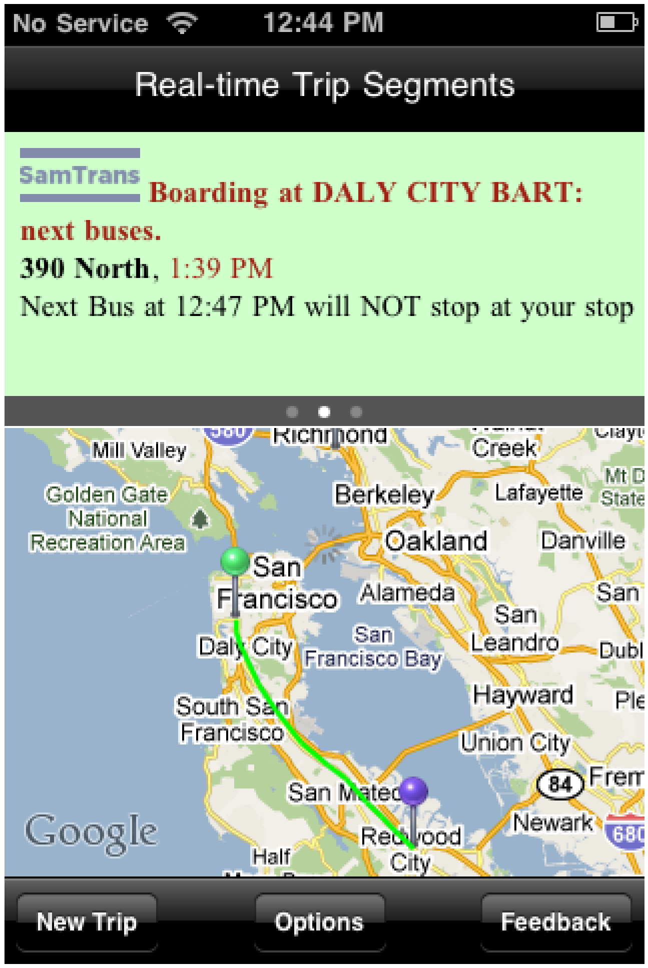


Figure 4-12 Mobile user interface (at train station)

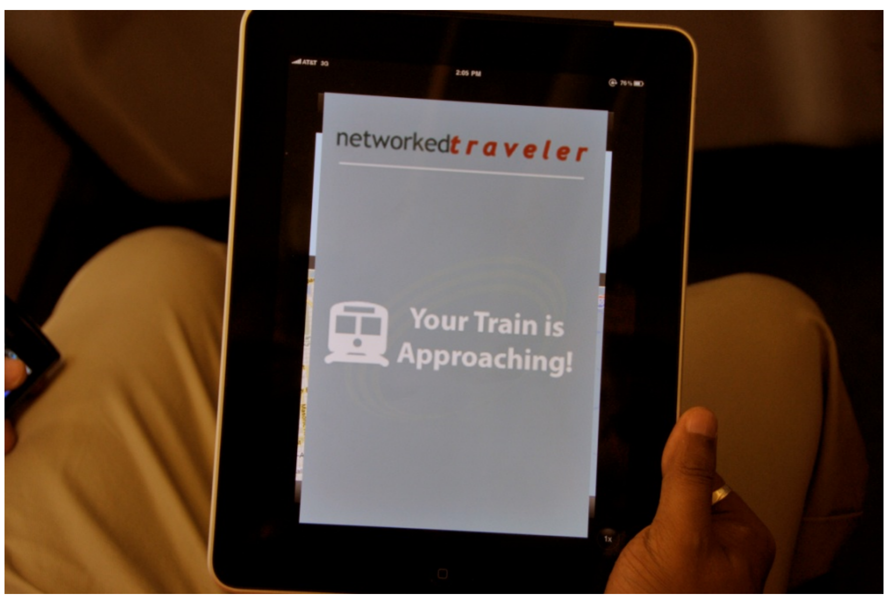


Figure 4-13 Alert given when train is approaching

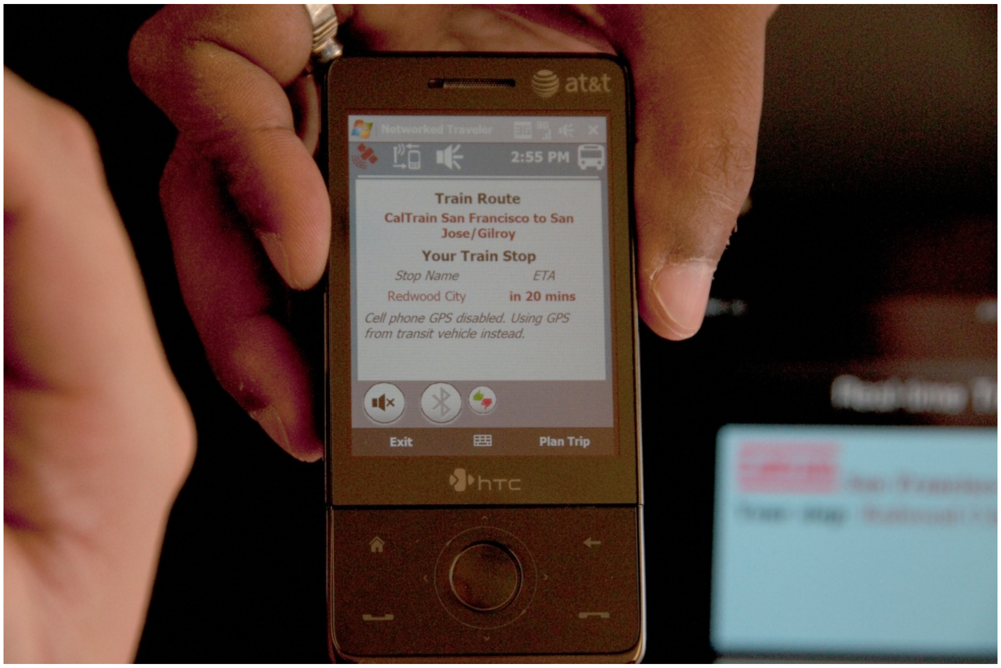


Figure 4-14 Mobile user interface when onboard Caltrain (User GPS turned off when matched with train GPS)

4.4. Geofencing

4.4.1. Geofencing Requirement of Networked Traveler Project

Under the Networked Traveler Project, the NT geofencing addresses the following traveler/cell phone use scenarios:

- **Disabling the NT application when the user is driving –** Under this scenario, the application will be disabled to ensure safety.
- **Enabling the application when the user is riding transit –** Under this scenario, the application will be allowed to be used.

A. Review of Existing Products for Networked Traveler Geofencing

The commercially available cell phone geofencing products reviewed in this document that are based on GPS speed, geo-locations or extra hardware devices are able to disable the usage of the phone while driving.

When applying the geofencing products for the NT project, the products that use the GPS speed for driver distraction prevention will NOT work because they will be falsely triggered when used on a transit vehicle, which are times when the application should not be disabled. Therefore the existing geofencing technologies based on detecting GPS speed or locations (either software only or software and hardware solutions) will not fit into the NT project's needs.

However the products that use an additional in-vehicle device for distracted driving prevention can conditionally solve the problem for cars that have the device installed. Moreover, the requirement of installing an extra device is usually costly, therefore is less desirable a solution for the geofencing needs of the project. For the NT project, we developed a geofencing function as part of the mobile software so that the use of the application can be disabled whenever the user is detected to be driving based on the GPS tracks and itineraries.

B. Geofencing Developed for Networked Traveler Project

The NT application uses the different movement characteristics for transit users/vehicles compared with that of private automobiles to differentiate the two travel modes (c.f. Figure 4-15). This is different from existing geofencing commercial solutions in the following ways:

- NT geofencing does not aim to provide a "driving detection" for the phone, rather, when the NT application is activated, NT geofencing disables the application if the user is detected to be in a moving non-transit vehicle. NT geofencing does not block phone calls or texting.
- When there is a trip submitted to the NT server, NT geofencing differentiates driving an automobile vs. riding on a transit vehicle, and allows the use of the application on a transit vehicle to deliver real-time passenger information updates. Since this geofencing function is part of the Networked Traveler system and has access to the users' trip itinerary data, it is able to identify the mode of the user while other software is not able to.

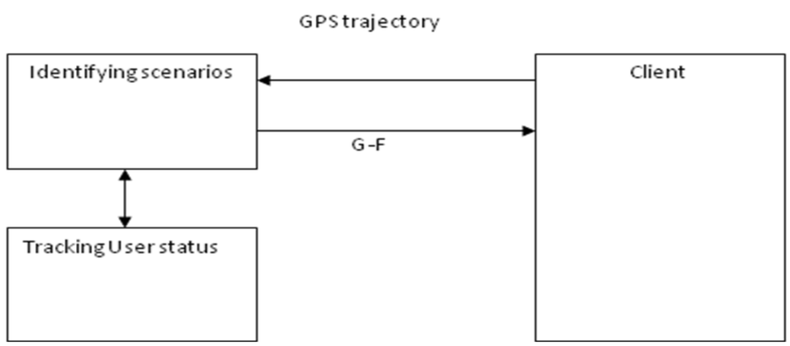


Figure 4-15 NT geofencing functional flow

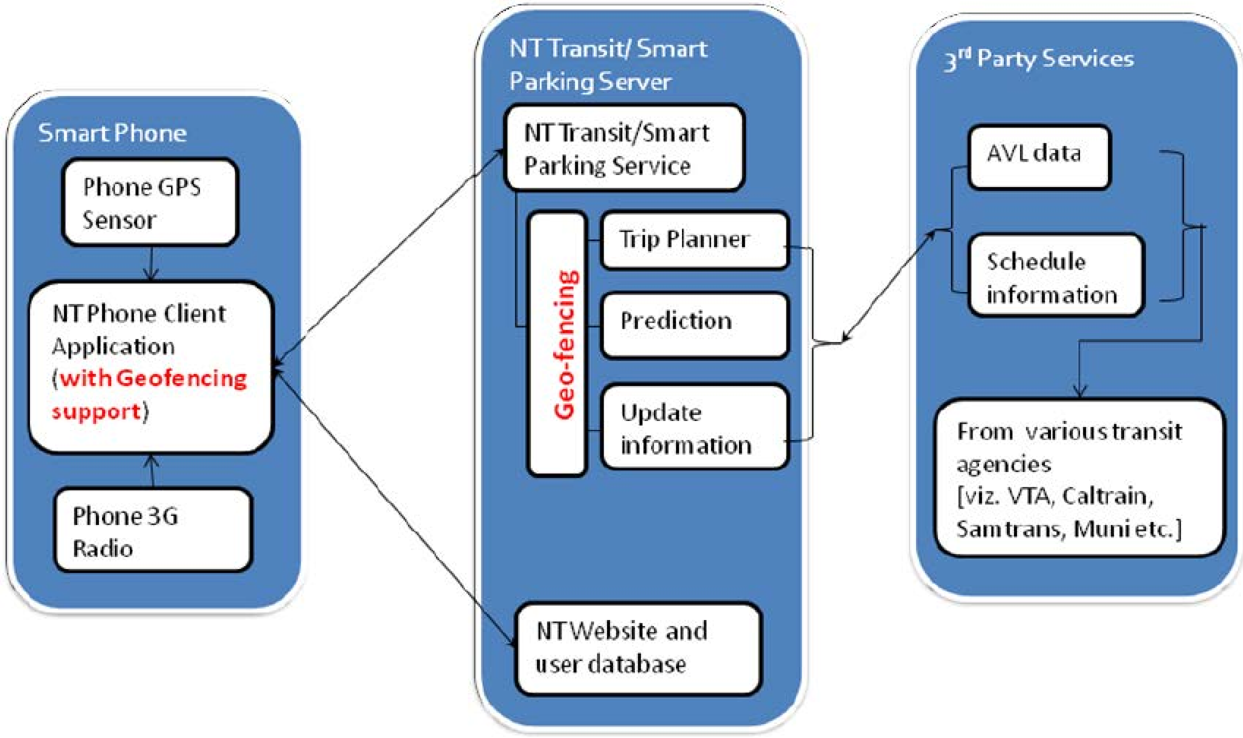


Figure 4-16 Geofencing design

The flow chart of the server-side geofencing logic is illustrated in Figure 4-16 and Figure 4-17. This server side implementation of geofencing logic allows a "thin" client design so that the complicated logic of matching the GPS location and identifying the activity of the traveler are taken care of at the server side to make the design on the client relatively easier, which benefits the implementation on multiple and different client target OS's including Windows Mobile, iPhone OS and Android.

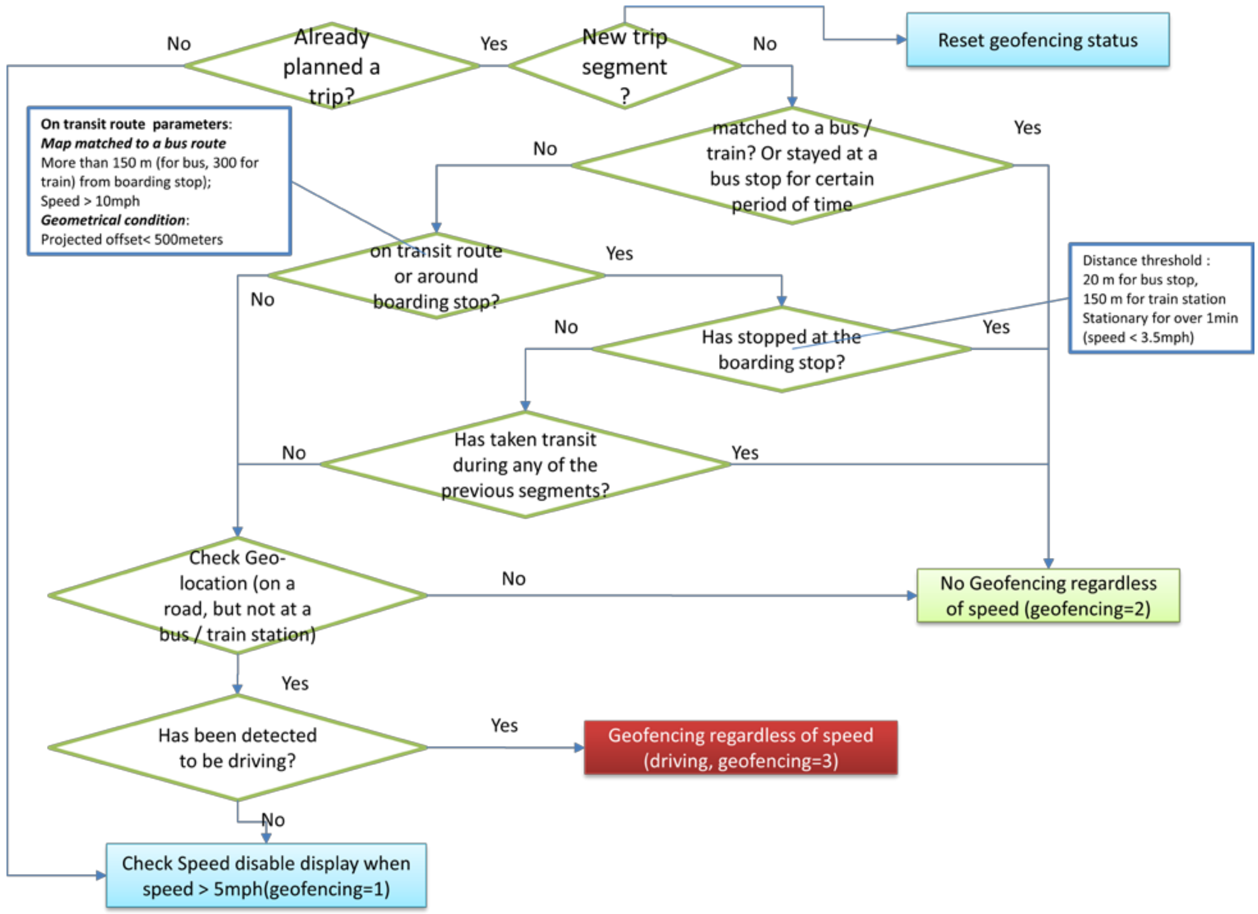


Figure 4-17 Geofencing flow chart

4.5. Using Bus Data as Arterial Traffic Probe: Experiment along El Camino Real

4.5.1. Overview

Besides the real-time traffic data for freeways, the real-time traffic data from arterials is also an important data source for IMTI. Under this project, we proposed to use a bus-as-probe approach to get the real-time traffic time along arterial roads.

The experiment was done along El Camino Real using the VTA BRT line 522.

4.5.2. Literature Review

The Bureau of Public Roads (BPR, Bureau of Public Roads, 1964) developed an equation model to calculate in-link travel time according to variation of the demand/capacity ratio. In comparison, the model in the Highway Capacity Manual (Transportation Research Board, 2000) specifically considers the impacts of traffic signal control. However, these methods are static and based on historical data. Therefore, they are not appropriate for real-time travel time estimation.

(Turner, Lomax, & Levinson, 1996), (Frechette & Khan, 1998)and (Zhang M. H., 1999) studied statistical models to estimate arterial travel time. They estimated relationships between link travel time and flow characteristics such as loop detector data, free flow speed, saturation flow and vehicles' spacing. These studies show relatively good estimation compared with the previous studies. However, these studies are site-specific, and their estimation methods are difficult to apply to other links.

Concerning these problems, many researchers focused on travel time estimation using real-time loop detector data and signal data on a microscopic scale. (Skabardonis & Geroliminis, 2005) developed an analytical model based on kinematic wave theory. They used loop detector data and signal timing data as input data. (Liu & Ma, 2008)studied a virtual probe vehicle model by using loop detector and signal timing data. They introduced a virtual vehicle into arterials and calculated the vehicle's trajectory based on Newell's car following theory. Then, they estimated the arterial travel time using this trajectory. These methods using real-time loop detector and signal data have advantages in processing traffic data and showing the real-time travel time. However, these approaches rely on point-detection at locations where loop detectors are installed and assume that loop detector data such as count, occupancy and speed represent flow characteristics at other locations on the link. Under this assumption, variations of flow characteristics along a road link cannot be captured.

To deal with this problem, probe vehicles on arterials are used to estimate travel time. (Hall & Vyas, 2000) compared bus probe data from the Orange County Transportation Authority with automobile trajectories and found that buses are likely to be delayed when automobiles have long delays. While the reverse situation is not always true. (Bertini & Tantiyanugulchai, 2004), (Uno, Tamura, Iida, & Yamawaki, 2002) and (Chakroborty & Kikuchi, 2004) developed a travel time estimation model by estimating the relationship between automobile and bus travel time after eliminating bus stop dwelling time. Recently, a fusion model using bus probe and loop detector data was developed to support travel time estimation when there are no probe runs (Berkow, Monsere, Koonce, Bertini, & Wolfe, 2009). However, there is well-known limitation of these previous studies. Because there is only one bus probe at the scheduled time in the case of using transit probes, it is hard to say that this bus probe represents all vehicles on arterials at the same time period even after using methods developed in the previous studies. For example, the bus probe might get good signal coordination on the arterial, but the other vehicles do not. In this case, the estimated travel time is much faster than the average travel time of other vehicles on the arterial.

4.5.3. Data Characteristics and Methodology

Second-by-second global positioning system (GPS) data is available for the whole Rapid 522 fleet. As probe vehicles for the purpose of measuring arterial performance, BRT buses have prominent advantages over local buses because BRT service is meant to be the transit service which is as efficient as driving personal cars. First of all, the BRT bus runs more like other traffic than the local bus does. Figure 4-18 illustrates three typical trajectories for a BRT bus, a local bus, and a testing vehicle, respectively. All the three vehicles started within the same time window to cross the same segment of El Camino Real. As shown in the figure, the cruising speeds, which are the slopes of curves, are somewhat different among the three vehicles. The local bus has much lower cruising speed than the test vehicle and the BRT bus. In contrast, the cruising speed for the BRT bus is quite similar with that for the test vehicle. There are three main reasons for this. The first one is that the advanced BRT vehicle allows them to accelerate rapidly and cruise with higher speed. The second reason is that BRT typically runs headway-based service, so it doesn't need to adapt their cruising speed and dwell time to meet the schedule at pre-defined check-points.

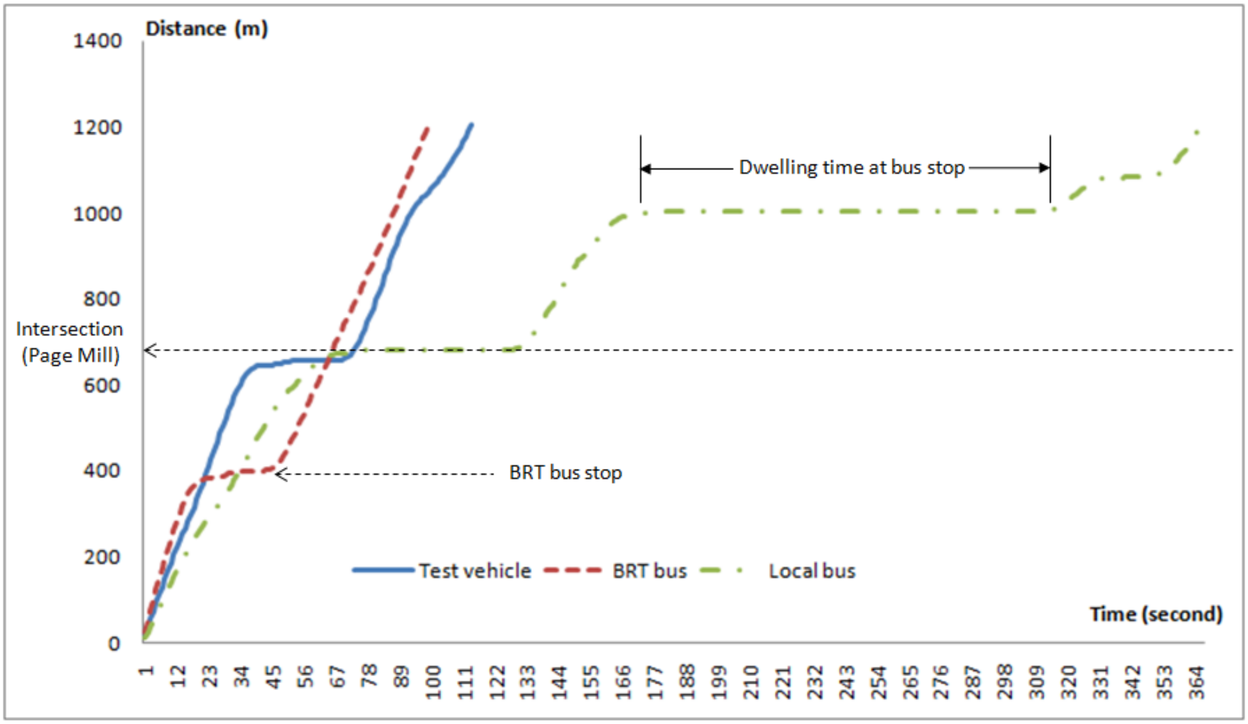


Figure 4-18 Trajectories of test vehicle, BRT and local buses

Third, BRT buses can flow more smoothly with other traffic because they don't have to stop as frequently as local buses do. For example, the bus stops for Rapid 522 are spaced approximately one-mile apart compared to stops spaced less than a quarter mile apart for local Line 22 serving the same route. Moreover, when BRT buses have to stop at bus stops and leave the major traffic platoon, transit signal priority (TSP) can help those buses catch up with the traffic platoon. As shown in Figure 4-18, the local bus has the longest delay, while the test vehicle experienced a shorter delay. The difference is partially due to the random arrival at the intersection. However, the reason why the BRT bus experienced almost zero delay is that this particular bus received prioritized treatment at the intersection. It is noted that BRT buses would need less TSP when flowing with major traffic platoons under coordination.

Although BRT buses have some advantages in the role of traffic probes, the travel time for BRT buses cannot be directly utilized as the arterial travel time for general traffic. There are three main factors that cause the travel time difference between BRT buses and general traffic. They are: (1) bus stop effects; (2) cruise speed differences with general traffic; and (3) traffic signal effects and signal coordination. The concept of our methodology is to filter the bus trajectory by eliminating the bus stop effects and differences of cruise speed and replace the intersection delay with average delay for general traffic.

The major difference between bus travel time and other traffic travel time is the delay caused by dwelling time at bus stops. The delay consists of three elements: stop time, deceleration delay and acceleration delay. To calculate these delays, it is necessary to detect whether a bus halts at a bus stop. Buses sometimes skip bus stops if there are no passengers to board/alight at bus stops. We check the bus's speed near the bus stop.

After detecting a bus's halting at a bus stop, the process to calculate deceleration and acceleration delay follows. To calculate these delays, we need to find out time points when a bus starts decelerating before halting at a bus stop and when it finishes accelerating after the departure from a bus stop. The GPS velocity from a running bus fluctuates due to 1) the dynamic nature of traffic conditions on urban streets and 2) GPS noise. A kinematic model was built to detect the vehicle approaching bus stop behavior from the GPS trajectories.

The delays caused by bus stops are eliminated from the bus travel time by subtracting stop time, deceleration and acceleration delays from bus travel time.

- Cruise speed

Cruise speed differences between bus and general traffic also contributes to their travel time difference. In almost all previous studies, researchers did not use BRT bus data but local bus data. Thus, they had to calculate the relationship between buses' and general traffic's cruise speeds. In this study, however, we used BRT bus data. Because the density of BRT bus stops is low, BRT bus drivers tend to use inner lanes rather than a shoulder lane. This characteristic makes it possible for BRT buses to run with a higher cruise speed compared with the local buses that mostly use the shoulder lane. When a BRT bus is not freely flowing due to congestion, other traffic typically slows down to run with a similar speed as the BRT bus does. Therefore, we can simply assume that if the BRT bus is not freely flowing, the velocity for other traffic is also the same as that for the BRT bus. Under free flow conditions, however, each mode might have different cruise speeds.

We processed second-by-second velocity data from a BRT bus and compared this with the data from a test vehicle. Each of the two vehicles was running along a 3-mile segment of El Camino Real during the same period and under free flow traffic conditions. The cumulative distribution function (CDF) of the free flow speed is shown in Figure 4-19. The velocities while accelerating or decelerating close to traffic signals and bus stops were excluded. As illustrated in the figure, the free flow speeds of both modes are very similar with each other. The average cruise speed for the test vehicle and the BRT bus are 17.5m/s and 17.6m/s, while their standard deviations are 1.37 m/s and 1.24 m/s, respectively. Furthermore, the result of statistical tests shows that there is no significant difference between both modes' free flow speed at the 95% significance level. This relationship has also been verified by using other sample probe data. Thus, we do not have to estimate the cruise speed relationship between two modes when estimating the arterial travel time.

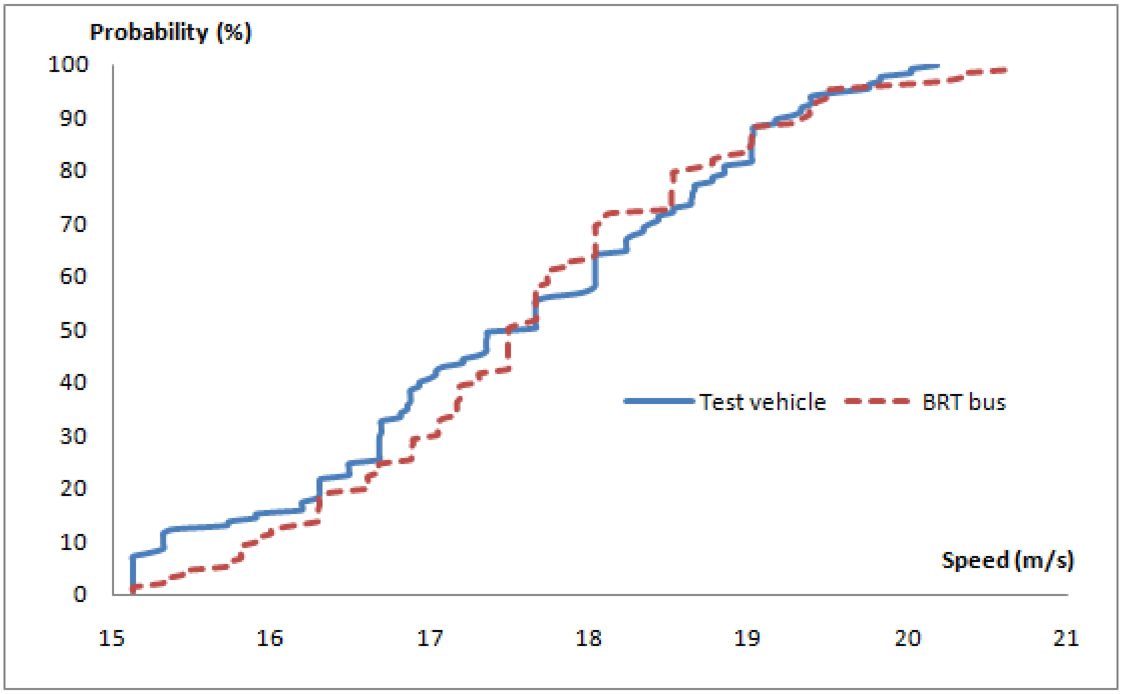


Figure 4-19 Cumulative distribution function (CDF) of cruise speeds for a BRT bus and a test vehicle

4.5.4. Application of Bus-as-a-probe Data in Path2go

The bus-as-a-probe real-time arterial traffic data is fed into the bus ETA prediction model to make the bus arrival time prediction results more adaptive to various traffic conditions. Moreover, the trip planning tool in Path2go system uses the estimated arterial performance information to provide dynamic planning results.

4.6. Real-time Parking Availability Detection at Caltrain Parking Lots

4.6.1. Wireless Sensors network based detection technology

There are several candidate technologies that can be used for detecting the availability of parking spaces in parking lots.

- Wireless Sensors network

  Using a few / many wireless sensors, including magnetic sensor / microwave sensors to sense the presence / movement of vehicles and send the information to the backhaul network using a wireless connection.

  One way of using a wireless sensor network is use sensors to detect the presence of a vehicle at a particular parking space. This approach will provide accurate and reliable data. The problem with this approach, also apparent, is that the cost is high when there are a large number of parking spaces. An alternative way is to use sensors at entrance(s) and exit(s) and/or along each aisle only to get the vehicle counts. This is a cheaper solution though it presents less reliable utilization results due to the error accumulation effect and when there are overnight parked vehicles, etc.

  Solution providers include IPS (integrated parking solutions), ParkingCarma, etc.

- Computer Vision (network)
  Using cameras to monitor and automatically detect the presence of vehicles. Econolite and Matsushita provide products and solutions of parking availability based on computer vision.

  Solution Providers include Matsushita, etc.

- Other sensing method
  Radar, Ultrasonic detector, etc.

A comparison of different sensing techniques is presented in Table 4-3.

Table 4-3 Comparison of Parking Lot Availability Sensing Technologies

Sensing technology	Solution	Hardware Cost	Pros	Cons	Choice
Wireless Sensors Network and entrance/exit only.	Use point detector which is capable of detecting vehicle movement at entrance and exit. Use SenSys sensor.	Medium cost	Lower cost compared to parking space sensing; All weather;	Error accumulation; Needs calibration;	√
Computer Vision	Mount cameras above parking lot to detect occupancy of parking lot	High cost	Reliable detection;	Open-space parking lot only; Less reliable in bad weather;	
Wireless parking space sensor network	Sensors at each parking space (or at only the parking spaces where drivers will last fill up)	High cost	Reliable detection. Can provide available space information; All weather; All-round.	High cost for large parking lots	

Due to the fact that many Caltrain parking lots (including RWC) have structures or underground parking facilities, computer vision is an excessively expensive option. And since there are usually hundreds of parking spaces per station, putting parking space sensors at each space would also be prohibitively expensive. So we have chosen the technology of using a wireless sensor network (Sensys technology) at the entrances/exits of the parking lot to collect vehicle in/out data and the ability to generate parking availability information indirectly.

We have tested the accuracy of Sensys sensors in measuring vehicle count and speed, using Pneumatic road tubes as the ground truth. Figure 4-20 below shows the histogram of speed measured from road tubes, and Figure 4-21 presents a comparison of speed measurement between road tubes and Sensys sensors. Results show the Sensys sensor can provide fairly accurate vehicle count and speed measures.

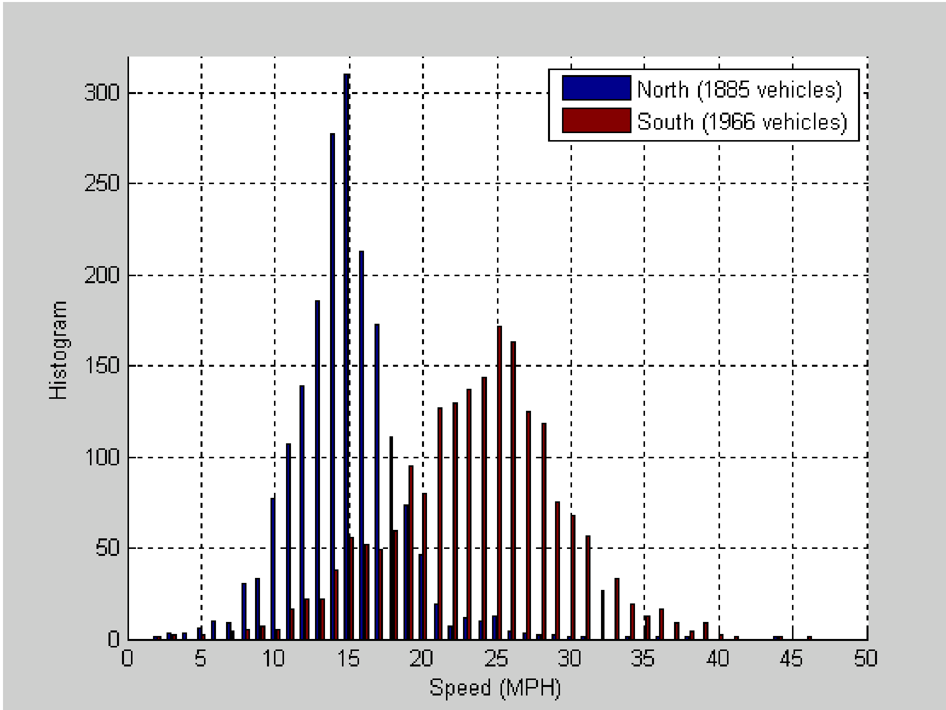


Figure 4-20 Speed Histogram of Pneumatic road tube measurement

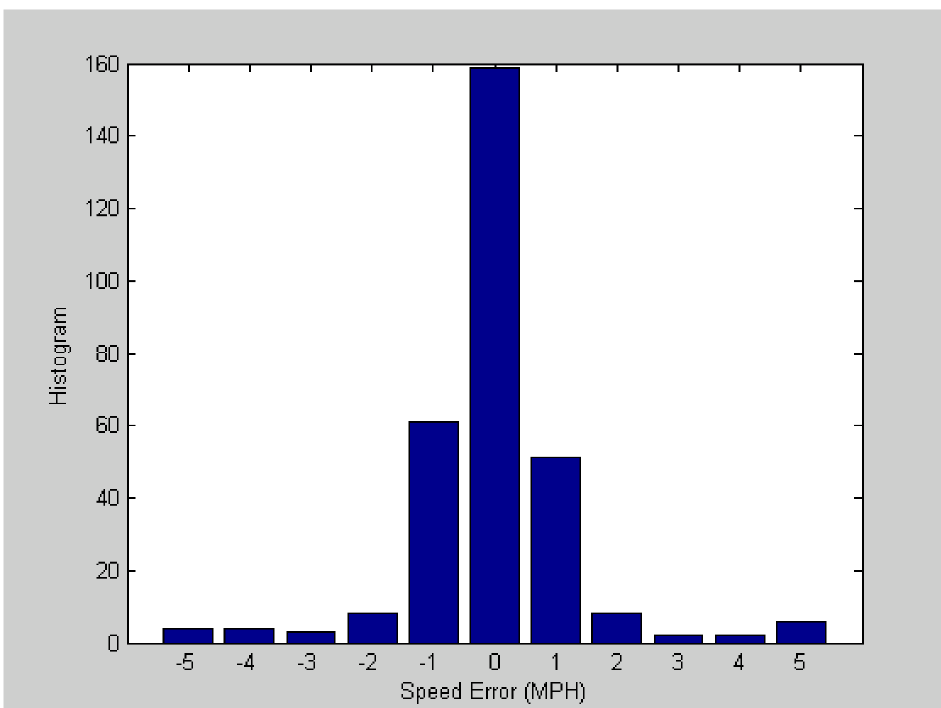


Figure 4-21 Comparison of Speed Measures by Pneumatic Road Tubes and Sensys Sensors

ParkingCarma has extensively studied the data processing technologies of Sensys outputs to get real-time vehicle counts. This technology can be readily applied to the parking availability data sensing and prediction issue (see Figure 4-22 and Figure 4-23).

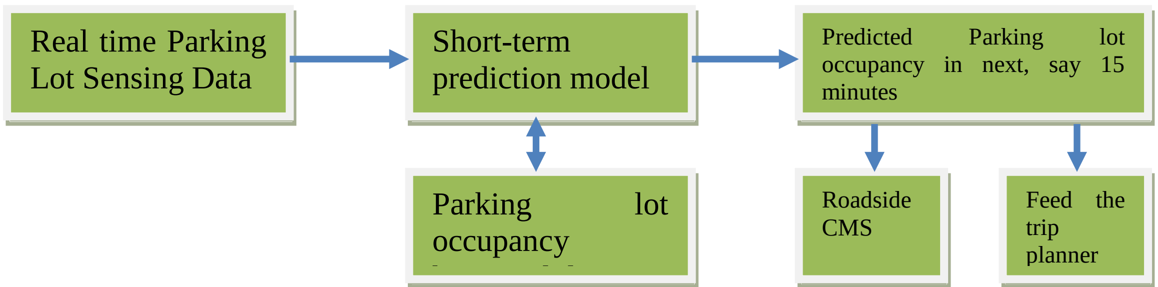


Figure 4-22 Parking Availability Data Processing

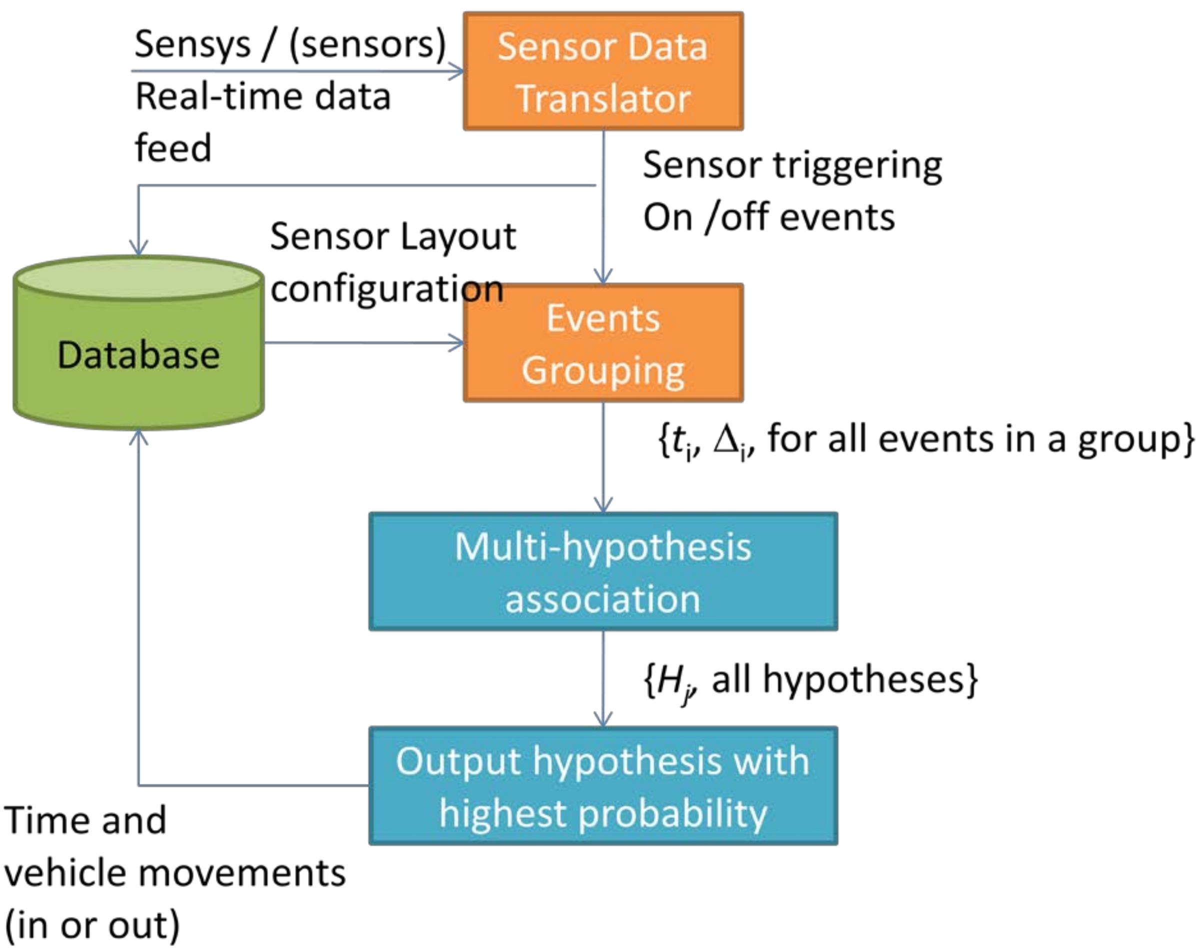


Figure 4-23 Parking Sensor Detection Model

4.6.2. Presentation of the Parking Occupancy Data

For parking space occupancy data, this information is provided to the passengers / drivers by means of coded messages (e.g., see the chart below).

Table 4-4 Color coding of parking availability information

Parking space not guaranteed (<= 20 available spaces)	Occupancy is high, not full ((20, 40))	Available (> 40

4.7. Reliable and Cost-Effective GPS Tracking for Automatic Vehicle Locations

A reliable and cost-effective GPS tracking system has been developed as an AVL (automatic vehicle location) system for the networked traveler project. The system is based on a traffic data collection system using mobile phone devices that had been developed under the Caltrans project "Improving Performance of Coordinated Signal Control Systems Using Signal and Loop Data (Caltrans task order TO6632)" and was modified to fit into GPS tracking purposes.

The GPS tracking devices have been installed on all buses of VTA BRT 522 line, all locomotives of Caltrain and 15 buses of the SamTrans bus fleet.

4.7.1. Overview

A cost-effective traffic data collection system which is based on existing mobile communication networks and Motorola iDEN[3] mobile handsets has been developed to be used as the GPS tracking system for the networked traveler project.

The objective of the system is to provide a cost-effective, reliable means to remotely collect GPS location data in real time from the buses and trains. On the cost side, the development of the system aims to achieve both a low device cost and low operational cost. Importantly, when viewed in terms of performance, the system is able to continuously provide over 2.68 kbps upload data rate per remote handset for more than 95% of the time, i.e., one remote handset could deliver data fetched from vehicles at a period of 200ms continuously.

[3] **Integrated Digital Enhanced Network (iDEN)** is a mobile telecommunications technology, developed by Motorola, which provides its users the benefits of a trunked radio and a cellular telephone. iDEN places more users in a given spectral space. (http://en.wikipedia.org/wiki/Integrated_Digital_Enhanced_Network)

The GPS tracking devices provide second-by-second GPS tracking information to the networked traveler server and the data are fused with other sources (ACS, third party sources, etc), processed and fed into the prediction module.

The GPS tracker data collection system includes remote GPS trackers for real time GPS data collection from buses and trains, a reliable wireless link based on the iDEN mobile network and highly scalable data centers with web based system management support.
The remote mobile phone is the Motorola iDEN 265 cell phone, which has an embedded GPS chip and a Java ME program support. We can write a customized program for the phone to deliver sampled GPS data back to a data center.
The iDEN wireless network serves as a cost-effective and reliable communication link for the system. The channel capacity limit is 9.6kbps. This data rate is adequate for the GPS tracker application and the service contract pricing for this network is lower for other available rate plans.
Highly scalable data centers and a web-based management system are also parts of the system. MySQL, an open–source, high performance database is used to store the collected data for further processing. The system is designed with a flexible architecture so that multiple data centers can be incorporated directly into the system as need or requirements dictate.
The system components are shown in Figure 4-24.

In summary, the system has the following features:

(1) Continuous real-time GPS data collection system structured for many data sources to transmit data simultaneously;

(2) Low system deployment and operational cost;

(3) Reliable communication based on an adaptive wireless link;

(4) Web-based system management that simplifies maintenance efforts

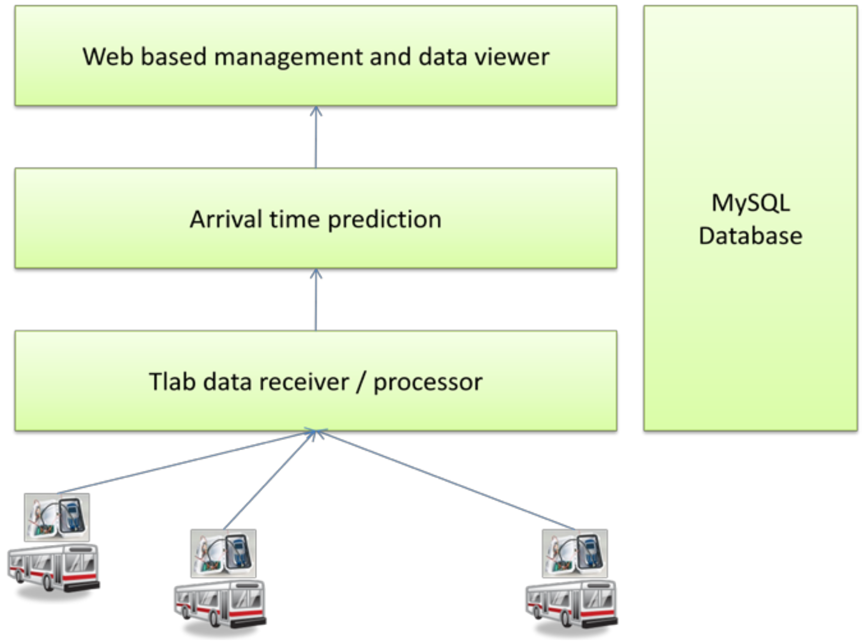


Figure 4-24 GPS tracker and data collection system

4.7.2. GPS Data Tracking System Ddesign and Implementation

A. GPS tracker hardware

Figure 4-25 GPS tracker

The GPS tracker is developed based on the iDEN 265 cell phone with extra hardware (as can be seen in Figure 4-25) for automatic powering on the phone if the cell phone lost power due to unpredictable reasons, therefore it is able to improve the availability of the data. Data center and data management

Data from various buses / trains are sent to one or more data centers and stored in a MySQL® database. Data are organized and processed using standardized database application interfaces and connectivity technologies, thus dramatically reducing efforts in maintaining, interpreting and analyzing the data.

A PHP based server program has been developed for viewing the status of GPS trackers in real-time. It has the following features (see Figure 4-26 and Figure 4-27):

- Visualize the GPS location on Google Maps;
- Sort by transit agencies;
- Show the status of the GPS tracker and the date / time of its last valid data received; mark as red when the tracker has been out-of-service for an excessively long time;
- Load historical GPS track data from database;

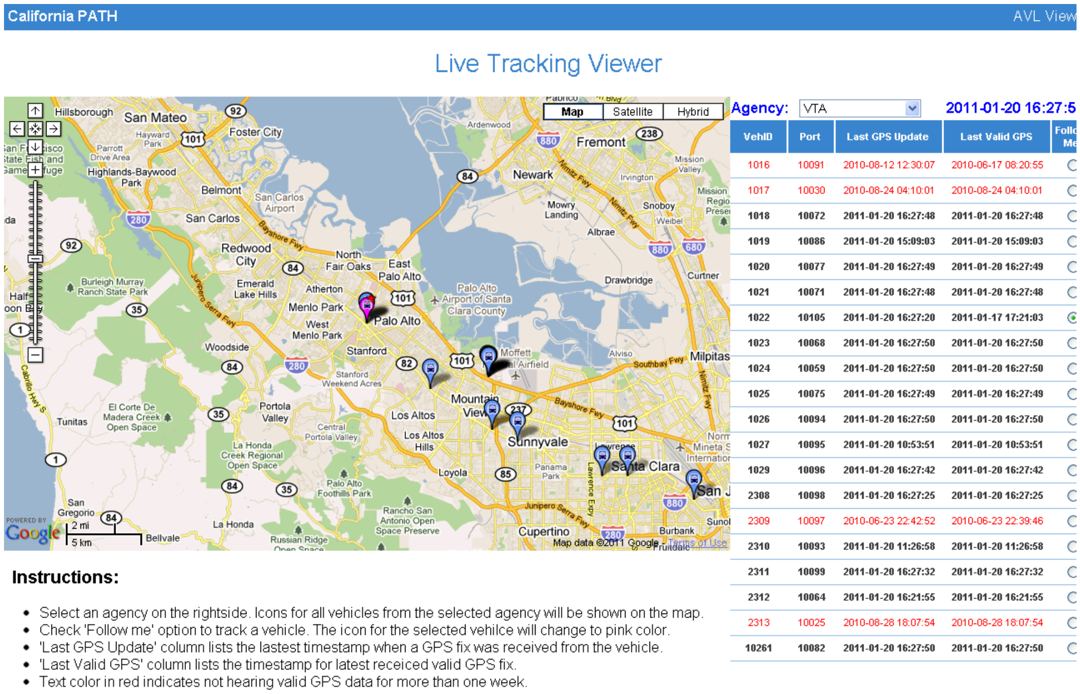


Figure 4-26 Live GPS tracker status

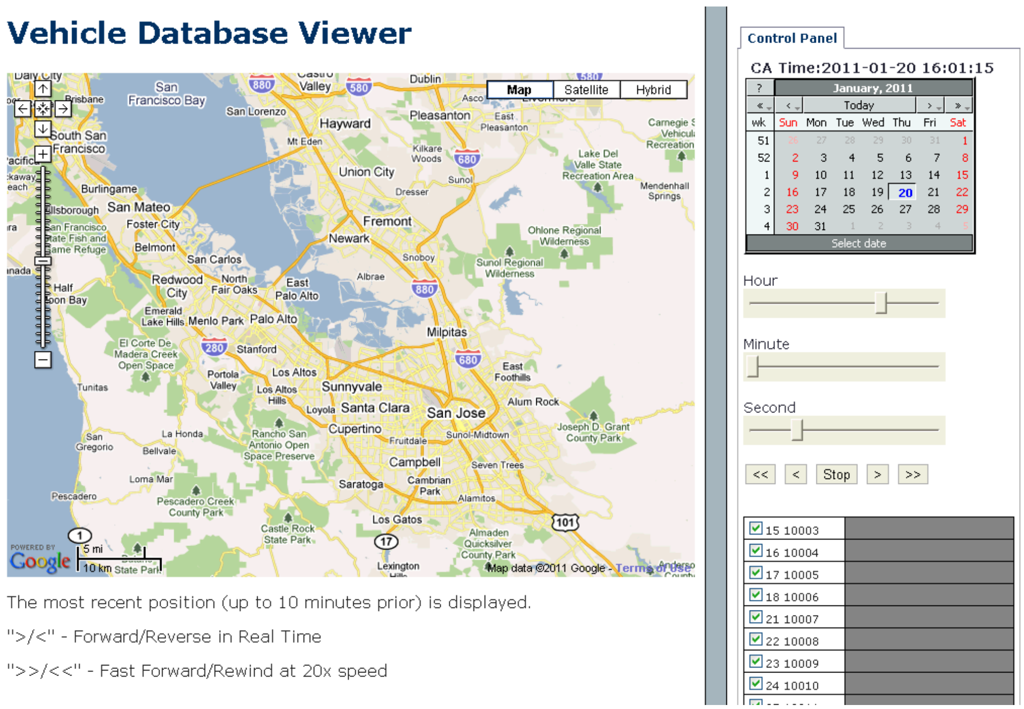


Figure 4-27 View saved GPS trajectories in database

5. Field Operational Test

5.1. Experimental Design

5.1.1. Premises

Taking commuter trains has become a viable alternative for travel. It is green and safe, and allows travelers to spend travel time on work, entertainment and rest as they wish rather than the driving task. Mode shift from SOV driving to public transit, e.g, commuter rail, can help balance traffic loads and provide congestion relief. Fuel price increases in 2008 has also triggered significant ridership increase. APTA Public Transit Ridership statistics (http://www.apta.com/research/stats/ridershp/index.cfm) shows that ridership remains high after fuel prices have reduced, indicating that when travelers are attracted to a transit mode, they tend to stay with transit. Several factors have discouraged travelers from using transit to commute, including:

(1) Unfamiliarity with where, when and how to take transit prevents drivers to shift mode regardless of the fact that transit can be competitive with driving in many cases.
(2) The lack of real-time information. Waiting at the station and looking for a parking space can be very time consuming and annoying, especially when a traveler is unable to find a parking space.
(3) Not knowing actual costs for traveling with auto mode is another factor for travelers to stay with the mode they are familiar with. Drivers typically think about only fuel costs when it comes to auto travel, but the expenses for auto travel include amortization for owning a vehicle, maintenance, insurance and license costs.

These travelers would likely be willing to use transit as an option once they became familiar with transit use. For these travelers, dynamic parking information together with real-time traveler information can help make commuting by train a viable option. A real-time parking information system together with comparative trip time information, presented through roadside Changeable Message Signs (CMS), and a pre-trip planning web site may potentially help travelers decide on a mode-shift in a number of ways:

(1) For the travelers who are familiar with train services but have been constrained by lack of available parking at their nearest train station, providing real-time information on parking availability for nearby stations including shuttle or transit connections at these facilities will encourage them to use train service more often.
(2) If the travelers who commute on highways are provided with congestion-related information, together with real-time Caltrain trip time and parking availability information, they will likely shift their mode to trains;
(3) Dynamic arrival time for trains and parking availability information will provide Caltrain users with better service, save travelers' time and make transit a more viable option.
(4) Real-time parking information in conjunction with route guidance can help reduce the time required to search for an available parking space.
(5) Information about comparative costs for available modes can likely trigger mode shift for some who are cost sensitive but do not comprehend all the details about their trip costs.

5.1.2. Test hypotheses

For each of the applications that are to be deployed for the field tests, the hypothesized outcome, expected benefits and user responses are described and listed in Table 5-1.

Table 5-1 Transit Application and Test Hypotheses

Application	Applicable Situations	Hypothesized Outcome	Expected Benefits to Travelers and their Response
Multi-modal pre-trip planner	• For users to make the plan while at home (e.g., make a plan to work);	• Travelers will benefit from the integration of the real-time train arrival time, parking availability information and freeway / arterial travel time. Travelers will be less likely to miss a train, or get the train station without being able to find a parking space. Train riding could become more viable to travelers.	• Travelers save time on waiting at stations, failed search for non-present parking spaces; • Travelers use transit more often; • Travelers provide favorable assessment of the real-time parking availability information
Multi-modal traveler information	• Caltrain arrival time at Train station and via smart phone • Get off alert and transfer information • Check Parking space availability information using a smart cell phone ;	• Travelers will get accurate train arrival time from either the message sign at station or via smart phones; • Travelers will get parking space availability information and next train arrival time from their smart phones; They might decide to take transit when they see the available parking space and a feasible waiting time; • Travels will get "preparing to takeoff" alert on smartphone;	• Travelers provide favorable assessment of the dynamic traveler information; • Traveler choose to take Caltrain instead of driving; • Travelers avoid missing the destination stop and benefit from fast alighting
Roadside Changeable Message Signs on Caltrain Parking Lot availability and Next Train arrival	• Put Changeable Message Signs (CMS) along US-101, where close to several exits to the test sites of Caltrain Stations, showing the real-time availability of the parking lot spaces and the next train arrival time;	• All commuters using US-101 will be able to benefit from the messages, not limited to the users that have downloaded our application into their smart phones.	• More commuters choose to shift mode to take Caltrain

There are a multitude of common elements given in the table above. They can be reorganized into the charts below. The first chart in Figure 5-1 is a diagram showing the suite of applications.

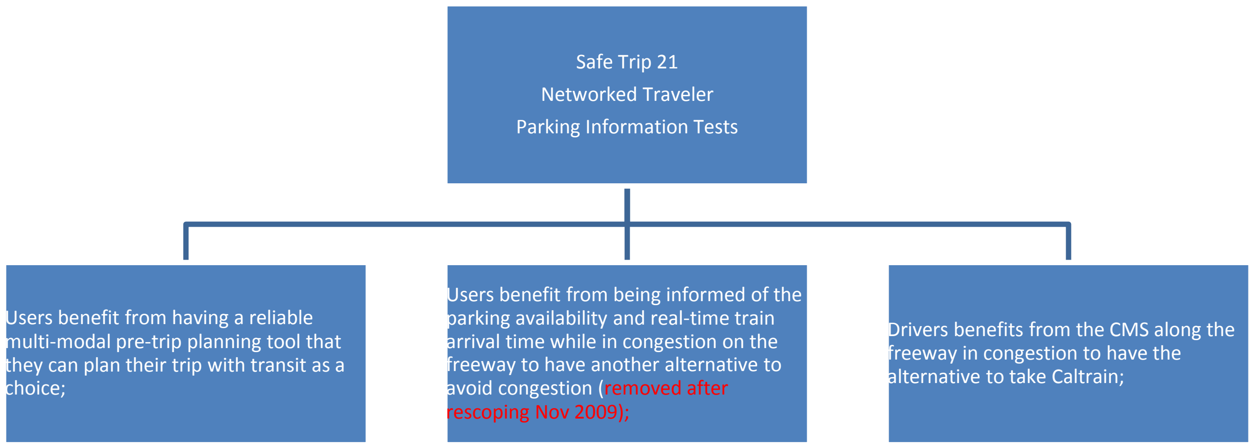


Figure 5-1 Hypothesized Expected Outcomes of Parking Information Applications

5.1.3. Validation of Test Hypotheses

A. Expected Test Outcome

Field data were collected and analyzed to explore the user needs and preferences. Design validity and shortcomings of the parking information applications will be evaluated.

The goal of providing the information, including the multi-modal pre-trip planner and the real-time parking availability information and transit real-time arrival time information, is to make the alternative of driving - taking transit - a more viable choice.

The idea is to help travelers make more informed choices potentially shifting their mode to transit, thereby helping to reduce congestion on the freeway and contribute to emissions reduction. The test will focus on how well travelers respond to the different ways of delivering the real-time multi-modal transit information and help them decide to shift mode.

The experimental design of the tests should focus on (1) the objective analysis of the data accuracy from the system perspective; and (2) the observation and analysis of user responses, both qualitatively and quantitatively. The second part will be done by the independent evaluator with support from the PATH project team.

We note that the user response data will be collected in different ways for different information delivery methods.

- Evaluate the generated information by the system with ground truth data that are either manually collected or generated by post-processing the second by second GPS data; The accuracy of the predictive bus arrival time and parking availability data can be evaluated this way;

- For the users that are using the multi-modal pre-trip planning applications / mobile phone applications, the user responses on their preferences and needs will be collected. Two forms of data collection will be made. First is to collect the user browsing history data, that includes when and how the users used the application, the frequency of usage, etc. Another form is the collection of user preference by asking users to take an on-line survey.

Through analysis the collected data for the different methods of information delivery, both the quantitative and qualitative part of system performance, can be measured.

For the transit oriented group of participants who take the multi-modal pre-trip planning application, the following procedure will be needed to collect experimental data:

(1) Users register for the service (User will need to register only once, after which users will only need to login with their user name) ;
(2) Users enter origin and destination for the intended trip (User can save the trip origin and destination as “home”, “work”, etc. for later usage. So the same user does not have to input the address of origin and destination each time).
(3) Upon each use, the user origin and destination will be sent to the server (and archived for later analysis).
(4) User preferences for the routes include: minimum travel time; minimum number of transfers; minimum driving distance to transit hub; minimum fare (with gas mileage in consideration), etc. User preferences will also be stored for analysis purposes;
(5) PATH server will generate routes according to the user preferences, based on real-time freeway travel time along US-101, real-time arrival times of the Caltrain trains, SamTrans and VTA buses and other static information including the schedule of BART;
(6) User confirms one choice, or cancels the planning and the action will be sent to the server and stored;
(7) System server receives AVL data from Samtrans and VTA for buses running along El Camino Real and Caltrain trains. Train and bus arrival time will be estimated in real-time by a PATH server and stored in the database; Server receives real-time freeway travel time data from an MTC server (one minute updating rate);
(8) The time of usage, the origin and destination, the user preferences and the user decision (the confirmed choice or void) will all be archived.

Constraints in Data Acquisitions

The following constraints in both quality and quantity of data acquisition should be noted:

(1) There are accuracy constraints for the various real-time data sources, which will in turn limit the accuracy and availability of test data collection:
    a. Parking data is subject to sensing errors, such that the parking space availability information may or may not be accurate. Therefore, the availability of parking spaces

will be encoded in a conservative way before being delivered to the travelers. Details will be discussed in the next section;

b. Freeway travel time from MTC has a one-minute sample period, plus link speed information from the MTC data is also subject to errors as have been observed during the feasibility study. The error will result in inaccurate traveler information (such as false alert of "park and ride message" when freeway travel time is excessively overestimated); error statistics will be obtained during the field test to build an alerting algorithm with error tolerance;

c. AVL data are only available for partial routes of SamTrans and VTA at the test sites; Whenever AVL data is not available, bus arrival time will be based on schedule only, which is subject to larger errors than real-time data;

(2) Constraints on obtaining user generated system data (including the user choices, user GPS track, user preferences, etc):

a. Subscribed users may or may not be using the applications during the test period. During user recruiting, we will make every effort to recruit relevant users, that is commuters that fit into the mode of our application and who use the route frequently enough. Of course the quality of the application itself will greatly affect the frequency of its usage by the users, which is also an MOE of the system: An application that is frequently used by the travelers should be viewed more positively;

b. GPS tracks of the subscribed user will only be collected upon consent of the user, and the user could stop sending the GPS data at any time during the test; the GPS track during the user commute, especially the trajectories before and after the user gets the "park and ride" alert are essential to know the action the user has taken; for safety concerns, we would rather not distract the driver by asking him/her questions or letting the driver press a button;

c. Accuracy of the GPS trajectories highly depends on the quality of the built-in GPS unit in the user's smart phone, which may be subject to outliers from time to time;

d. Users may or may not travel between the prescribed origin and destination;

B. Measures of Effectiveness

The field tests of the applications is on a limited scale, and considered a pilot test as it is to be carried out within a limited period of performance and scope. However, it is still important to establish the framework and methodology to conduct the system assessment toward the end of the pilot test so that effectiveness and usefulness of IMTI applications can be properly measured. Table 5-2 illustrates how a matrix of measures of effectiveness can be constructed.

Table 5-2 Anticipated Test Outcomes and Measure of Effectiveness

Expected Test Outcome and Traveler Responses	Measures of Effectiveness (MOE)	Parameters and Variables to Assess MOE
Public awareness of parking information	• Spectrum of project partnerships	• List of partners in project • Scope of participation by partners

Expected Test Outcome and Traveler Responses	**Measures of Effectiveness (MOE)**	**Parameters and Variables to Assess MOE**
applications		• List of participating organizations outside of project team
	• Scope of community participation	• Number of participating users • Number of data samples collected in field tests • Percentage of positive feedback by users
	• Outreach efforts	• Sessions of activity reports held in public forums and conferences • Technical papers presented • Reports of media events
Favorable user experience and positive user feedback to the multi-modal pre-trip planner	• Willingness to participate and to maintain continual use of the application	• Number of participating users • Periods of active usage • Continuity and frequency in activating applications • Percentage of positive feedback by users
	• User feedback to surveys and questionnaire on - Functional usefulness - Functional acceptability - User interface friendliness - Information accuracy (in terms of predicted parking space availability, predicted train arrival time, etc);	User answers in surveys and questionnaires
Mode shift actions	• User Mode shift	• Frequency of user activating the

Expected Test Outcome and Traveler Responses	Measures of Effectiveness (MOE)	Parameters and Variables to Assess MOE
by users: "Park and ride" alert and CMS information (*No longer applicable after the rescoping of the project*)	actions	application of "Park and Ride" alert; Percentage of samples when a mode shift is seen after "Park and Ride" alert is given to the traveler; • Percentage of users (based on survey data) ever shifted / or would shift mode upon seeing each CMS information ; Time saving preferences to switch mode (from user perspective)
	• User feedback to the information • Timeliness of alert • User interface friendliness • Information accuracy • User feedback on CMS message content	• User provides favorable feedback to the information: User thinks the information provided by "Park and Ride" alert and CMS information are useful to travelers to make mode shift decisions;
Objective information accuracy	• Accuracy of bus /train arrival time prediction results • Accuracy of the encoded parking space availability information	• Compare bus/train prediction results with ground truth data obtained by post-processing second by second GPS data from buses /trains • Presented encoded parking lot availability information as compared to the ground truth (can only be done for several days when ground truth data is available (surveyors to count the parking lot occupancies);
Geofencing functionality	Verify that Geofencing functionality is implemented and works to prevent usage while driving	Testing under certain predefined scenarios to verify for each scenario whether or not the geofencing logic can successfully identify the situation and behave properly.

5.1.4. Data collection and analysis

A. User Recruiting

Targeted Users

There are two groups of users that we targeted to recruit for the applications:

- Commuters that frequently take transit (Caltrain) to San Francisco from San Mateo County and Santa Clara County;
- Commuters that frequently drive(-alone) to San Francisco from San Mateo and Santa Clara County;

Table 5-3 User Recruiting Cities and Population Size

Commuter group	Commuters that frequently ride trains		Commuters that drive-alone	
User applications	Multi-modal Pre-trip planner		“Park and ride” alert and CMS information	
destination of the commute	San Francisco		San Francisco	
Will recruit users from these cities:	Redwood City, Menlo Park, East Palo Alto and Palo Alto		Millbrae, San Mateo, Redwood City	
Number of the population of users that match the condition in the candidate cities:	Millbrae-Burlingame	~300	Millbrae-Burlingame	~6000
	Redwood City San Carlos	~500		
	Menlo Park East Palo Alto	~200	San Mateo-Coastside	~4600
	Palo Alto	~ 500	Redwood City San Carlos	~3600

In Table 5-3, we listed the population size of the users that we targeted to recruit. The calculation is based on the year 2000 San Francisco Bay Area Census data and also the year 2008 Caltrain Annual Report. Note that the Caltrain report does not have destinations included, so the number of train riders is indicated as Northbound only, not necessarily to be destined for San Francisco, though most of them are assumed to be.

The selection of the users based on their origins and destinations, as well as their commuting mode, should significantly increase the quality of collected data.

B. *Definition of Samples for the Applications*

A sample is defined here as basically one usage of the applications of one alert occurrence. For different tests, the sample size requirement would be different. Also there are two dimensions for the sample size, one is the number of participants in the test while the other is the number of repeated experiments per participant. Focus on which dimension depends on the application. Table 5-4 shows a sample definition for the applications.

Table 5-4 Sample Definition for Applications

Test	Sample
Multi-modal Pre-trip Planner: User Feedback	A sample is one set of yes / no feedbacks from one user, to the survey questions such as usefulness, interface friendliness, data accuracy (about predicted parking space availability, train arrival time, etc).
"Park and Ride" Alert: User Mode Shift Actions (no long applicable)	A sample is one trip trajectory data, including the GPS track, the time when the alert message is given to the driver, and the post-processed result of whether or not the driver followed the advice;
"Park and Ride" Alert: User feedback Actions (no long applicable)	A sample is one set of yes/no feedbacks from a user to the survey questions about the usefulness and user friendliness of the presented information;
CMS information: User feedback	A sample is one set of yes/no and multiple choice feedbacks from a user to the survey questions about the usefulness and accuracy of the presented information;
Objective accuracy of parking space availability information	Will be continuous data records on the parking space availability; Test will be based on data collection period of time instead of sample size;
Objective accuracy test of "bus / train arrival time prediction" alert	The accuracy in terms of error and variance actual arrival time versus the predicted arrival time ;
Geofencing functionality	One sample is one scenario,

C. Sample Size Estimation

The required sample size for the experimental tests are calculated based on the type of the survey, margin of error, confidence level and the candidate population size, if applicable. Table 5-5 shows sample sizes for the applications.

Table 5-5 Sample Sizes for Applications

Expected Traveler Response	Assumptions	Sample Size
1. Traveler provides favorable feedback to "Multi-modal Pre-trip Planner"	1.Dichotomous (Yes/No) Outcome 2. Margin of error =5 % 3. Confidence level =95 % 4. Population size= ~1,500 5. Response distribution=50% (50% is the worst case which requires the most samples)	306 (or with sample size as low as 100, the margin of error would be 9.5%)
2. "Park and Ride" Alert: User Mode Shift Actions (no longer applicable)	1.Dichotomous (Yes/No) Outcome 2. Margin of error =5 % 3. Confidence level =95 % 4. Population size= ~14,000 5. Response distribution=10 % (We are expecting this percentage to be quite low)	137 (or at a sample size of 100, the margin of error would be 5.86%)
3. "Park and Ride" Alert: User feedback positively (no longer applicable)	1.Dichotomous (Yes/No) Outcome 2. Margin of error =5 % 3. Confidence level =95 % 4. Population size= ~14,000 5. Response distribution=50 % (Worst case)	374 (or at a sample size of 100, the error margin would be 9.77%)
4. CMS information: User feedback positively	1.Dichotomous(Yes/No) Outcome 2. margin of error =5 % 3. Confidence level =95 % 4. population size= ~14,000 5. response distribution= 50% (worst case)	374 (or at a sample size of 100, the error margin would be 9.77%)

Expected Traveler Response	Assumptions	Sample Size
5. Objective accuracy of parking space availability information	Continuous measurement, will use mean square error (MSE) to measure the accuracy of availability data and the error probability of critical mis-coding of the coded data (such as encode full parking lot as not full);	One week of continuous data collection;
6. Evaluation of the accuracy of bus / train arrival time prediction	Continuous measurement, will use mean square error (MSE) to measure the accuracy of predicted arrival time	One~two month
7 Geofencing functionality	Test for all the predefined scenarios	All pre-defined scenarios

D. Data Collection

As outlined in the application rollout schedule and milestones above, the parking information applications were made available in June 2009. Corresponding to this schedule, the data collection was implemented in several stages:

Quantitative Data

(1) Collection of user data in response to the applications
After the initial validation period, the data collection will continue as long as the user opts to activate the functions in his/her commutes.

(2) Collection of parking availability data
Parking availability data is an important data source to the smart parking project. It feeds data for all the three applications: the multi-modal planner, the CMS information and the "Park and Ride" alert. So the accuracy of the parking space availability information is vitally important to the success of the project.

The experimental test of the parking availability information will be based on a manual survey of parking space occupancy, which will be used as ground truth data for verification of the vehicle sensing and parking space prediction algorithm output.

- Data collection sites
  - Instrumented Caltrain stations, to include Millbrae, Redwood City, Menlo Park and Palo Alto.
- Data collection period of time
  - One week
- Data
  - Record the time up to seconds of each vehicle leaving and entering a given parking lot. Each surveyor will do only one parking lot of a station per day.
  - Record each entering or leaving vehicle, including its time. If multiple vehicles enter or leave at almost the same time and it is difficult to distinguish the time separately, they will be recorded as a group.
  - The processed parking space occupancy data for the given parking lot (if instrumented);
  - The encoded parking space availability information based on the detection algorithm (The encoding procedure will map the number of available spaces to a discrete state indicating the likelihood of getting a parking space);

(3) Collection of CMS travel time log data.
The log data show how often the CMS signs display that riding the Baby Bullet has a time advantage over driving on US-101. The data can be correlated with the survey results to evaluate the CMS system performance.

User Survey and Questionnaire

User survey forms will be provided to the two groups of travelers.

(1) User information at registration
All users are required to register when they sign up for the application services. In this registration process, certain questions about the users will be posed. Answers to some questions are required, and others are optional. For example, to assess the coverage of the user base, the driving distance and zip codes for origins and destinations of regular routes will be useful information to have in this registration process. The detailed form of questions will be provided later.

(2) On-Line Feedback
Users will be given the option of providing anytime feedback on problems encountered in the use of the applications as well as desired changes or suggestions on the applications that are offered.

(3) Mid-term Survey

During the field testing period, users can give feedback using the online survey link at any time.

(4) Final Survey

One month before the project concludes, users will be asked to go through another survey. This will be another milestone to assess the user experience as well as to observe any noticeable changes in user experience after exposure to the applications for an extended period. After the final survey, unless the user opts to discontinue the service, data will continue to be collected, which may be valuable for later evaluation of the field tests.

Qualitative data to assess user subjective experience of the applications will be collected through surveys and online feedback. The types of data that can potentially be collected include the following, but the exact form and questions of the survey will be developed later:

- Overall impression of applications
    - Usefulness
    - Interface friendliness
    - Reliability
    - Issues or problems in using applications
    - Preferences
- Traveler background information
    - Age
    - Gender
    - Familiarity or experience with smart phones
    - Origin-destination
- Traveler experience with specific applications
    - How often traveler uses the application (or sees the message sign) daily or weekly
    - How frequent traveler receives the information
    - Which information is most useful (or the traveler thinks may be useful to other drivers in general);
    - Specific problems encountered with individual applications
    - Recommended changes

5.2. Timeline for the System Testing and FOT

There have been multiple system subtests, system testing and FOT events happening during the project period. Hereby we make a chart to illustrate the timeline of those events as shown below in Figure 5-2 and Table 5-6.

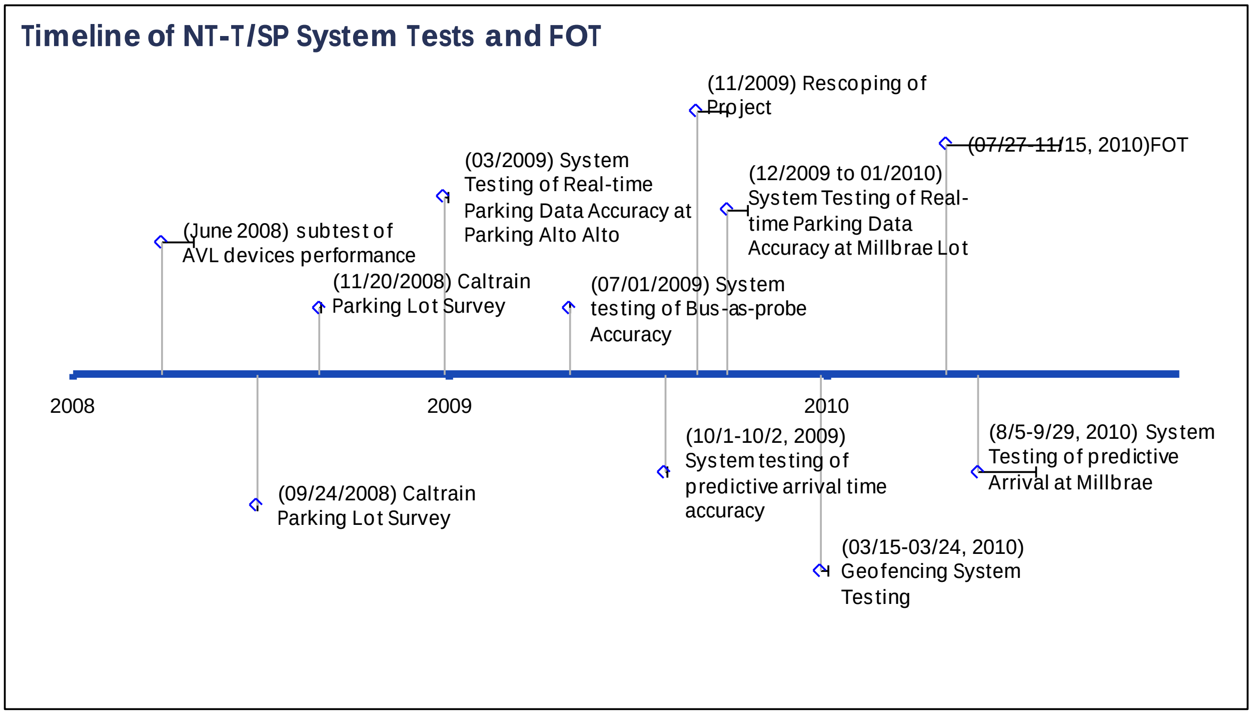


Figure 5-2 Timeline of System testing and FOT

Table 5-6 System Tests and FOT

Date	Task	Days
Jun-08	**(June 2008) subtest of AVL devices performance**	30
Sep-08	**(09/24/2008) Caltrain Parking Lot Survey**	1
Nov-08	**(11/20/2008) Caltrain Parking Lot Survey**	1
Mar-09	**(03/2009) System Testing of Real-time Parking Data Accuracy**	5
Jul-09	**(07/01/2009) System testing of Bus-as-probe Accuracy**	1
Oct-09	**(10/1-10/2, 2009) System testing of predictive arrival time ac**	2
Nov-09	**(11/2009) Rescoping of Project**	30
Dec-09	**(12/2009 to 01/2010) System Testing of Real-time Parking Da**	20
Mar-10	**(03/15-03/24, 2010) Geofencing System Testing**	7
Jul-10	**(07/27-11/15, 2010)FOT**	110
Aug-10	**(8/5-9/29, 2010) System Testing of predictive Arrival at Millbr**	55

5.3. Summary of the System Testing and FOT Results

Before we explain in detail the results of the system testing and FOT, we summarize their results and compare them with the MOEs and hypotheses developed for the project in this section.

System testing and the FOT are for two different purposes. Via the system testing the objective performance of the Path2go system, mainly the accuracy of its data (predictive arrival, parking data), and major functionality were tested using quantitative measures. While for the FOT, the usage data and user survey data were later collected to support quantitative and qualitative evaluation of the effectiveness of the Path2go system and its information.

5.3.1. Summary of Results for the System MOEs

The system MOEs were listed in 5.1.3 Validation of Test Hypotheses. In this section, we will list the test results corresponding to the MOEs (Table 5-7).

Table 5-7 Measured Performance

Expected Test Outcome and Traveler Responses	Measures of Effectiveness (MOE)	Expected Performance	Measured Performance
Public awareness of the applications	• project participation: Project Partners	• N/A (qualitative MOE)	• CCIT, ParkingCarma, Navteq, SamTrans, VTA
	• Scope of participation by partners	• N/A(qualitative MOE)	•
	• List of participating organizations outside of project team	• N/A (qualitative MOE)	•
	• Scope of community participation o Number of participating users o Number of data samples collected in field tests	• Enough users so that usage and survey result data can result in meaning statistics (e.g., error margin less than 10%)	• Participated Users: 783 mobile users; • Web users: over 1000; • Error margin for survey results: less than 10% • achieved √
	• Outreach efforts o Sessions of activity reports held in public forums and conferences o Technical papers	• N/A (Qualitative)	• Four technical paper presentation (2 on ITS World Congress 2010, 2 on TRB Annual Meeting 2011) • Won Outstanding paper award on ITS WC 2010

Expected Test Outcome and Traveler Responses	**Measures of Effectiveness (MOE)**	**Expected Performance**	**Measured Performance**
	presented o Reports of media events		• Berkeley Press Release • Media Reports (See 5.5 for details) (See Appendix F for more details of the outreaching efforts)
Favorable user experience and positive user feedback to the multi-modal pre-trip planner and mobile application	o Willingness to participate and to maintain continual use of the applicationNumber of participating users o Periods of active usage o Continuity and frequency in activating applications	• Frequency usage of the application • Steady growth in the users and numbers of usage • Time on site / mobile application	• Results are based on analysis from objective usage data (two data sources: Server logs and Google Analytics results. Analysis showed results from the two data sources were consistent) D. Steady growth of number of users during the FOT (Independent Evaluation report, 2011) E. Steady usage of web and mobile application with fluctuations (overall usage grew steadily) , (Independent Evaluation report, 2011), see also 5.6.5 for details F. Relatively low returning users, however as pointed out by the evaluation report, this is expected behavior for web / mobile phone applications. √
	• User feedback to surveys and questionnaire on - Functional usefulness - Functional acceptability - User interface friendliness	• Favorable feedbacks to the survey questions	• Results are based on the voluntary survey collected on the project website during the FOT and the final survey after project finished.

Expected Test Outcome and Traveler Responses	Measures of Effectiveness (MOE)	Expected Performance	Measured Performance
	- Information accuracy (in terms of predicted parking space availability, predicted train arrival time, etc);		***Overall Evaluation***: √ Good (66.7%) Neutral: (27.5), only 5.9 bad ***Usefulness of information***: √ Over 70% agree/strongly agree Path2go is useful. Less than 6.0% disagree /strongly disagree. (Final survey 56%-65% versus 14%-10%) ***Information Accuracy***: √ 66% agree/strongly agree versus 6% disagree/strongly disagree (Final survey: 40% versus 12%) ***Helps to reduce waiting time at bus / train stop***: √ 74.6% agree/strongly agree, versus 9.8% disagree /strongly disagree. ***Encouraging Mode shift (Consider Transit as more viable option)***: 64% agree/strongly agree versus 6% disagree/strong disagree Likelihood for modeshift: (32.1 % yes versus 29.5% no)

Expected Test Outcome and Traveler Responses	Measures of Effectiveness (MOE)	Expected Performance	Measured Performance
			There was one aspect that received relatively low user perception, which is the user interface design and usability. Higher percentage of survey respondents indicated that the information was not very well organized.
Mode shift actions by users: "Park and ride" alert and CMS information (No longer applicable after the rescoping of the project)	• User Mode shift actions • Frequency of user activating the application of "Park and Ride" alert; Percentage of samples when a mode shift is seen after "Park and Ride" alert is given to the traveler; • Percentage of users (based on survey data) ever shifted / or would shift mode upon seeing each CMS information ; Time saving preferences to switch mode (from user perspective)	• N/A (dropped after rescoping)	• Dropped after rescoping We still have such a question in the final survey and the result is : ***Have you ever changed your route***: 13.3% yes, versus 86.7% no.
Objective information	• Accuracy of bus /train arrival time prediction results	•	• **Good results achieved for** Arrival Time

Expected Test Outcome and Traveler Responses	Measures of Effectiveness (MOE)	Expected Performance	Measured Performance
accuracy	• Accuracy of the encoded parking space availability information		Prediction accuracy: √ o on average about 0.6 minute for predictions over 10 minutes before the arrival at the stop. The 75 percentile error is less than 1.7 minutes (VTA buses) o on average less than 0.5 minute error for prediction over 10minutes before the actual arrival, 1.5 minutes over 20 minutes before arrival (SamTrans bus routes) • Good results for accuracy of parking availability data √ o Counting error: 1% over 2 weeks of testing o Overall error (calibration error of overnight parking): average less than 3% • Accurate Arterial performance measure results: o Travel time: RMSE 9%, o Level of service: accuracy 73%
Geofencing	Verify that Geofencing functionality is implemented and works to prevent	Testing under certain predefined scenarios	A total of 20 trips were made during testing. Geofencing successfully detected 19 trips out of 20.

Expected Test Outcome and Traveler Responses	Measures of Effectiveness (MOE)	Expected Performance	Measured Performance
functionality	usage while driving	to verify for each scenario whether or not the geofencing logic can successfully identify the situation and behave properly.	The failed trip was because there was a bus following the car. √

5.3.2. Sample Size and the Error Margins of the Survey Results

The FOT data for the MOE of "favorable user experience and positive user feedback" came mainly from two data sources: the online survey results during the FOT and the final survey conducted by the independent evaluator after the FOT was finished.

Major questions of user perception of the application in terms of usefulness, accuracy and effect in encouraging mode shift were included in both analyses. Therefore the number of respondents is combined for an error margin at the 95% confidence level of analysis.

- Number of online survey responses during the FOT: 51
- Number of final survey responses : 121 (c.f. independent evaluation report)

Table 5-8 Sample Size and Achieved Error Margins

Expected Traveler Response	**Expected Sample Size**	**Sample Size and achieved error margins (@ 95% confidence level)**
• Traveler provides favorable feedback to "Multi-modal Pre-trip Planner" –	306 (for 5% error margin) **90 (for 10% error magin)**	
o Overall rate of Path2go		Error Margin at 172 sample size: 6.61% √
o Usefulness of the information		Error Margin at 172 sample size: 6.61% √
o Information was accurate		Error Margin at 172 sample size: 6.61% √
o Feels more confident about transit service		Error Margin at 121 sample size: 8.54% √
o More likely to choose an alternative mode (transit)		Error Margin at 172 sample size: 6.61% √
o Have you ever changed your route based on Path2go		Error Margin at 121 sample size: 8.54% √

Expected Traveler Response	Expected Sample Size	Sample Size and achieved error margins (@ 95% confidence level)
• Objective testing of accuracy of predictive arrival time	One month of data	Data collected for over a month √
• Objective testing of parking data accuracy	Two weeks	More than two weeks at Millbrae station and more than two weeks at Palo Alto √

5.4. System Testing and Performance Analysis

This part of the FOT is to analyze the data collected from the field to evaluate the objective quantitative measurements of the system, including the two major aspects mentioned in the experimental design: (1) accuracy of bus / train arrival time information; (2) accuracy of parking detection.

In addition to the data accuracy analysis, other aspects of the system performance are also evaluated, including the data communication reliability and the information availability rate.

Therefore system testing is carried out to quantify the following measures of system performance:

- Data accuracy (predicted arrival time, parking)
- Communication delay / outage
- Other critical measures which indicate whether the system is working properly: (rate of giving out alerts correctly, rate of the user getting real-time updates vs. schedule-based updates).

5.4.1. AVL Data Performance

The AVL system is a core component of the system and the performance of which has a great impact on the overall performance of the Path2go services. Therefore the AVL performance needs to be evaluated to make sure the quality of AVL data can meet the requirements of Path2go services.

Measurements for the AVL system are listed below:

- iDEN Service Availability
  - Percentage of package loss and outage due to network connection issues
- iDEN network data communication latency
  - End to End Latency
- AVL data Updating Rate
  - Consecutive GPS update rate at data server
- The statistics of eight cell phones and one data center over 10 days were averaged to form the following performance indexes as shown in Table 5-9.

Table 5-9 AVL System performance indexes

Performance	Average	Definition
Instantaneous throughput	619Bytes/s	Number of bytes received per second by the data center from one cell phone, measured every 10 seconds. *Note: these statistics do not include measurements taken when there is a communication outage.*
AVL data availability	99.6%	The number of bytes received by the data center divided by the number of original bytes sent by the signal controller to the cell phone, measured

Performance	Average	Definition
		every hour
AVL datas Latency	2 s	The time a packet takes to travel from the source (only the GPS message has its original time stamp, so the source originates from the GPS satellites) to the data center. Due to a lack of high resolution timestamp, the latency is estimated to be roughly 2s in most observations.

The average throughput data was obtained for all the clients undergoing the test. The tests were carried out at Richmond Field Station. Details of the testing results can be found in Appendix G.

5.4.2. Predictive arrival time performance

A. VTA BRT 522 and CalTrain

The accuracy of the arrival time prediction results need to be evaluated from two different perspectives. One is the objective evaluation that compares the prediction results to the actual bus /train arrival times (obtained from post processing the GPS data) and learns the objective accuracy of the predictions. Another one is the users' perspective consisting of user feedback statistics on the accuracy of the arrival time prediction results when presented as part of en route transit information. For the second part, we will present the evaluation results based on user survey responses

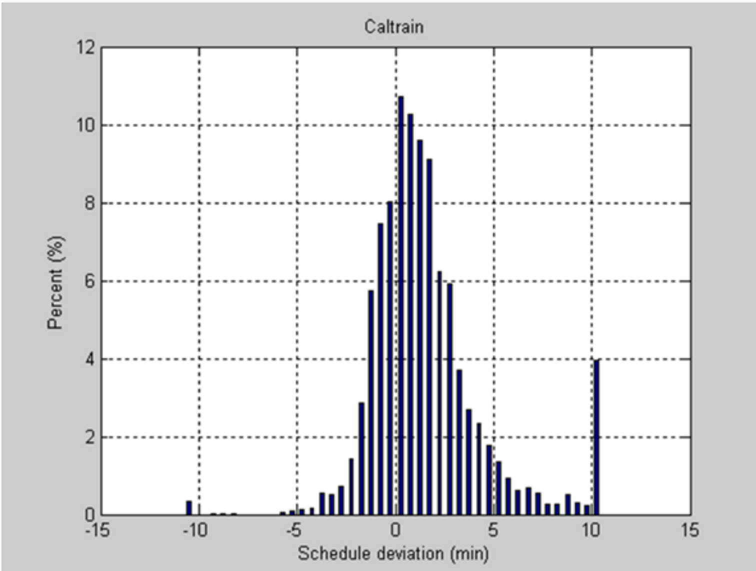
The MOEs of the arrival time prediction include

- Successful transit trip association rate (number of the trips that real-time predictive arrival time information is available)
  - Percentage of trips that train/bus is sending GPS data back to data server
  - Percentage of AVL data being latched with a transit trip
- Prediction error
  - Time difference between predicted arrival time and actual arrival time

For a successful association rate, the test was conducted on Oct 1st and Oct 2nd, 2009.Total number of trips made was 14 (7 train trips + 7 bus trips). The total number of the trips that successfully showed real-time information was 12 (7 train trips + 5 bus trips) with a rate of 85.7%.

The missed trips were mainly because of the powering of the AVL devices. Bus drivers sometimes forgot to turn on their headlights as they are supposed to do. The AVL devices are powered by the headlight circuitry.

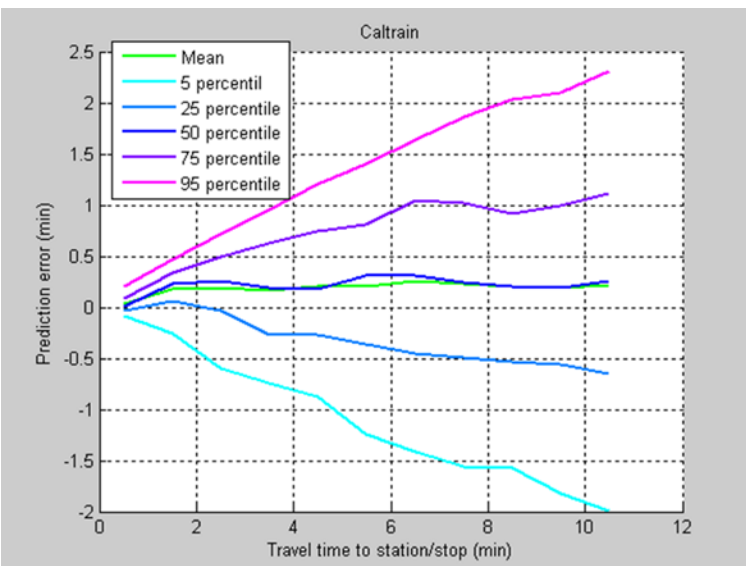
The prediction accuracy is measured by the time difference of predicted arrival time and actual arrival time (Figure 5-4). The error of schedule deviation is also calculated. The data used was from September 28th 2009 to October 2nd 2009.



Caltrain Schedule Deviation

Mean: 1.98 minutes
5 percentile: -1.50 minutes
25 percentile: -0.05 minutes
50 percentile: -1.30 minutes
75 percentile: 2.85 minutes
95 percentile: 8.71 minutes

Figure 5-3 Caltran Schedule Deviation



Caltrain predictive Arrival Time Deviation

Mean: 0.25 minutes
5 percentile: -1.80 minutes
25 percentile: -0.6 minutes
50 percentile: -0.25 minutes
75 percentile: 1 minutes
95 percentile: 2.2 minutes

Figure 5-4 Caltrain Arrival Time: Actual vs Predictive

The results showed that the mean deviation of the Caltrain predictive arrival time is on average approximately 0.25 minute for prediction over 10 minutes before the arrival at the stop. The 75 percentile error is less than 1 minute (Figure 5-4).

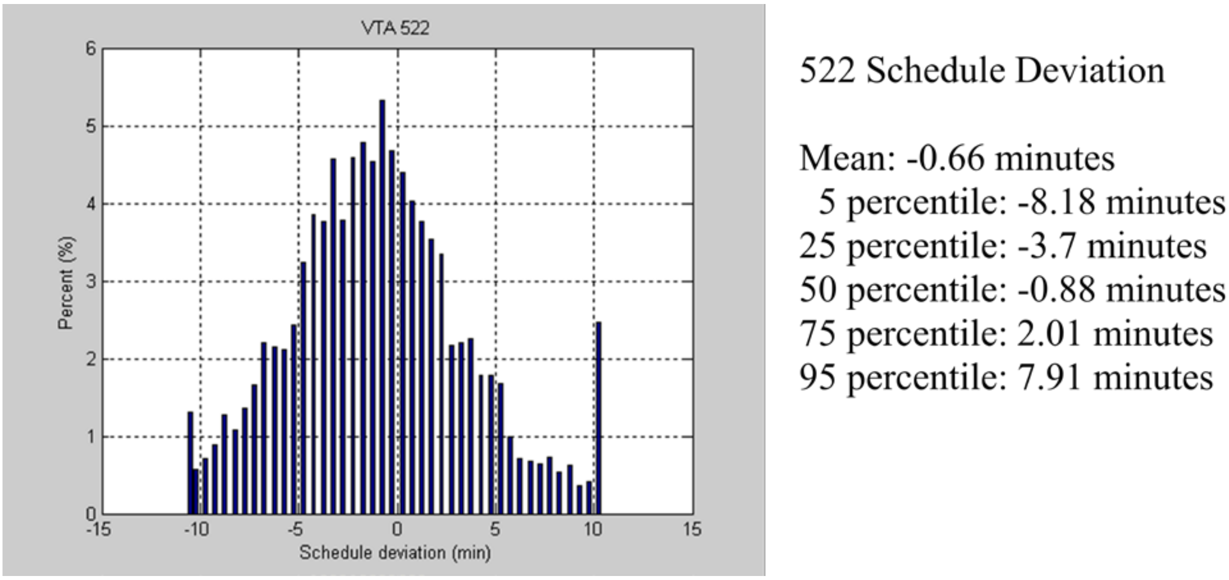


Figure 5-5 VTA 522 Schedule Deviation

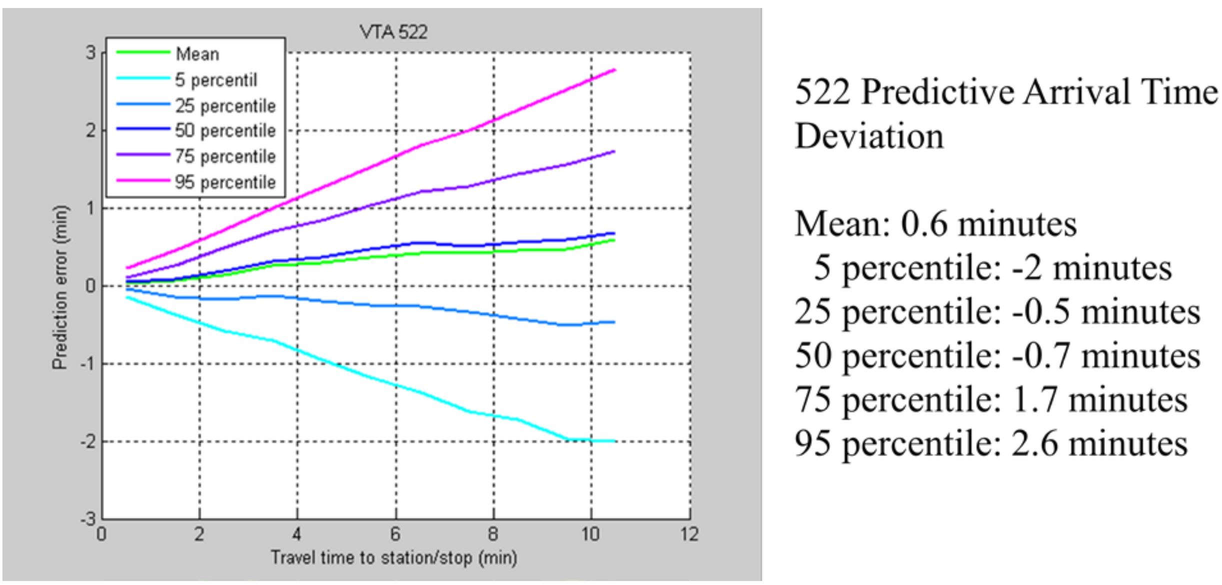


Figure 5-6 VTA 522 Arrival Time: Actual vs Predictive

The results showed that the mean deviation of the VTA bus predicted arrival time is on average about 0.6 minute for predictions over 10 minutes before the arrival at the stop. The 75 percentile error is less than 1.7 minutes (Figure 5-6).

We have also conducted system testing of the real-time predictive arrival time at the Millbrae Transit Center for selected SamTrans bus routes.

Millbrae Transit Center is the largest intermodal terminal in the United States west of the Mississippi River (see http://en.wikipedia.org/wiki/Millbrae_Intermodal_Terminal). It provides cross-platform connections for BART, Caltrain, and 4 SamTrans bus lines, i.e., 359, 390, 391 and 397. Predicted bus arrival information for the 4 SamTrans lines are displayed at the Millbrae station. Figure 5-7 and Figure 5-8 below show the station for one SamTrans line and the real-time arrival information display, respectively.

Figure 5-7 Millbrae transit center

Figure 5-8 Kiosk display powered by Path2go predictive arrival time at Millbrae transit center

Prediction accuracy was evaluated using 181 northbound trips on SamTrans route 390 and compared with the case of using its schedule as the prediction (Route 390 northbound trips provide service from Palo Alto Transit Center to the Daly City BART station). Figure 5-10 below shows the evaluation result.

The accuracy of arrival time prediction was evaluated for major SamTrans routes at the Millbrae station. Figure 5-9 shows the performance of intersection arrival time prediction. The curves in the plots are percentile lines of the prediction error. For example, the percentile line with the "95" mark indicates 95% of time the prediction error is below the line and 5% of time the error is above the line. The "50" percentile line is the average error of the prediction, as a function of actual travel time to the intersection.

The predictive arrival time has shown to be accurate at the Millbrae station (Figure 5-10). The prediction error was also compared with the case that a customer relies on the bus schedule as the estimated bus arrival time.

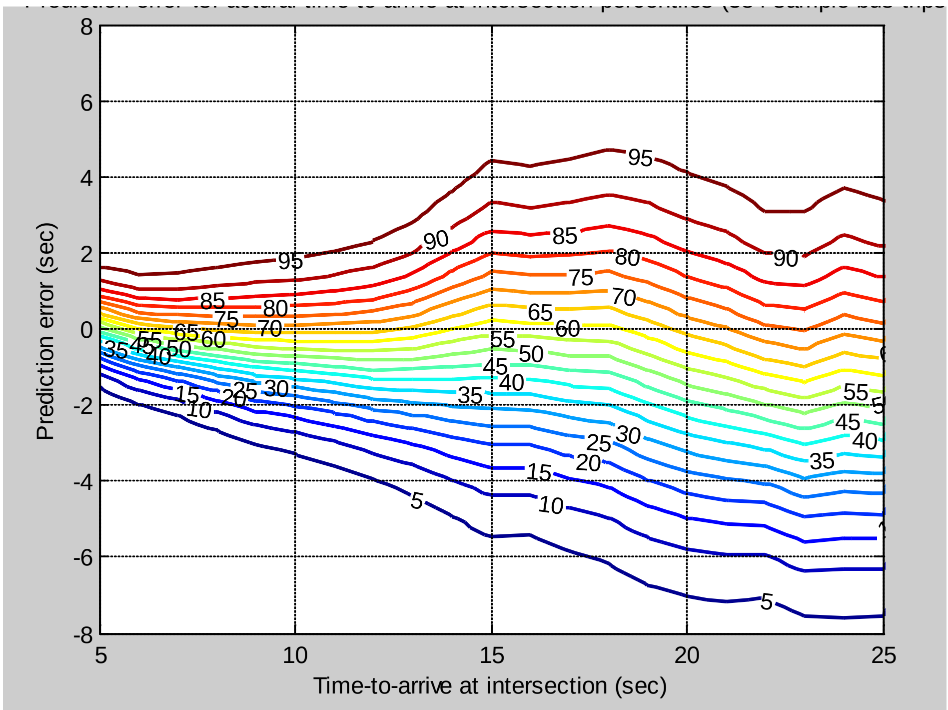


Figure 5-9 Prediction Error vs. Actual Travel Time to Intersection

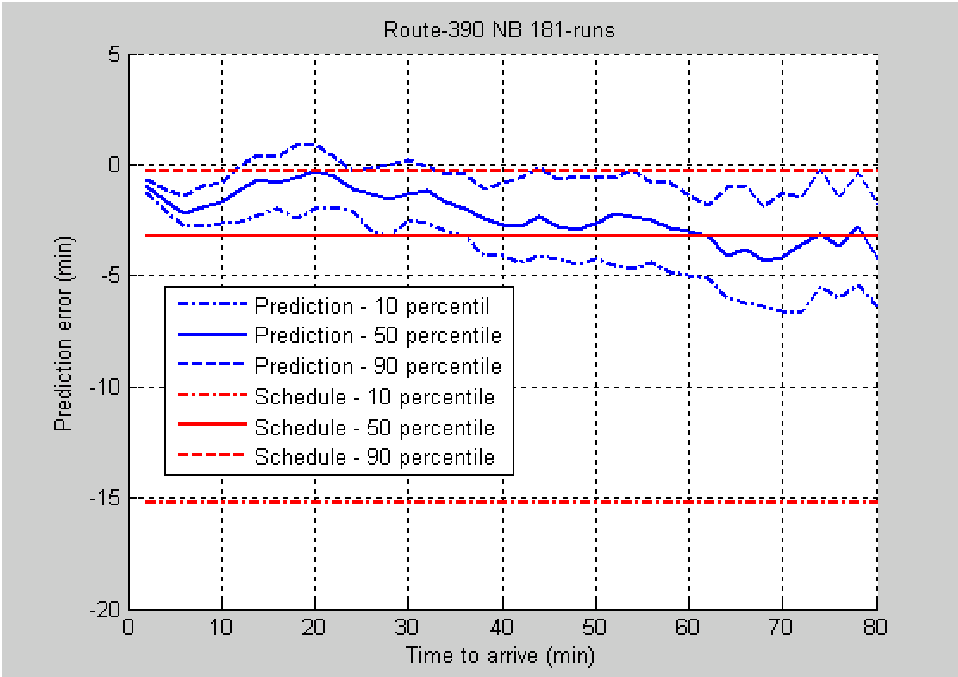


Figure 5-10 Prediction Error vs. Actual Travel Time to Bus-Stop (At Millbrae station)

5.4.3. Performance analysis of the bus-as-a-probe travel time estimation

To verify the effectiveness of the developed method, we conducted a field test along a 3-mile segment of the three-lane arterial El Camino Real in Palo Alto, California between Oxford Avenue and Jordan Avenue. This section is a part of the VTA Rapid 522 bus line. There are only 3 bus stops in this section with 15 signalized intersections.

To measure the travel times for general traffic, we used the license plate matching method. After the installations of three video cameras at each side of the test site, we recorded license plates of all approaching vehicles from 5PM to 7PM on July 1st 2009. The total number of vehicles arriving at the origin and the destination were 3,399 and 3,461, respectively. The number of matched license plates was 497, which is 14.36% of all arrival vehicles. On average, it was about 83 sample travel times per 15-minute period. Although this license plate matching method did not give detailed trajectories, it provided enough samples to calculate a good ground truth of arterial travel time, which helped us calibrate and verify our model.

Based on the collected bus trajectories, the parameters for the bus stop model have been calibrated. The threshold velocity V^{stop} and the radius of bus stop area R were determined as 3*m/s* and 20*m*, respectively, in this study. It is noted that the threshold values can be different for other sites and different GPS devices due to various levels of reception strength and data accuracy.

By assuming traffic is only delayed by traffic signal control and the resulting queues, the average intersection delay for all traffic is simply the average trip travel time minus the free flow travel time. The signal waiting time for all traffic was calculated by using the imaginary trajectory method. The queuing delay is the difference between the intersection delay and the signal waiting time. The average intersection delay for bus probes can be calculated by filtering the bus stop effects and cruise speed differences. The bus waiting time at signals was calculated based on the signal status data and the time when the bus departed the upstream intersection. The bus queuing delay is the difference between intersection delay and the signal waiting time. Figure 5-11 shows the comparisons of total intersection delay and queuing delay for all traffic and buses, respectively. According to the results, the bus probes and all traffic have similar intersection delay and also queuing delay. If we compare the model to use bus intersection delay to estimate average traffic intersection and the model to use bus queuing delay to estimate average traffic queuing delay, we found out the root mean square error (RMSE) for the queuing delay model is 34.9*sec*, which is about 9% better than 37.9*sec* for the intersection delay model.

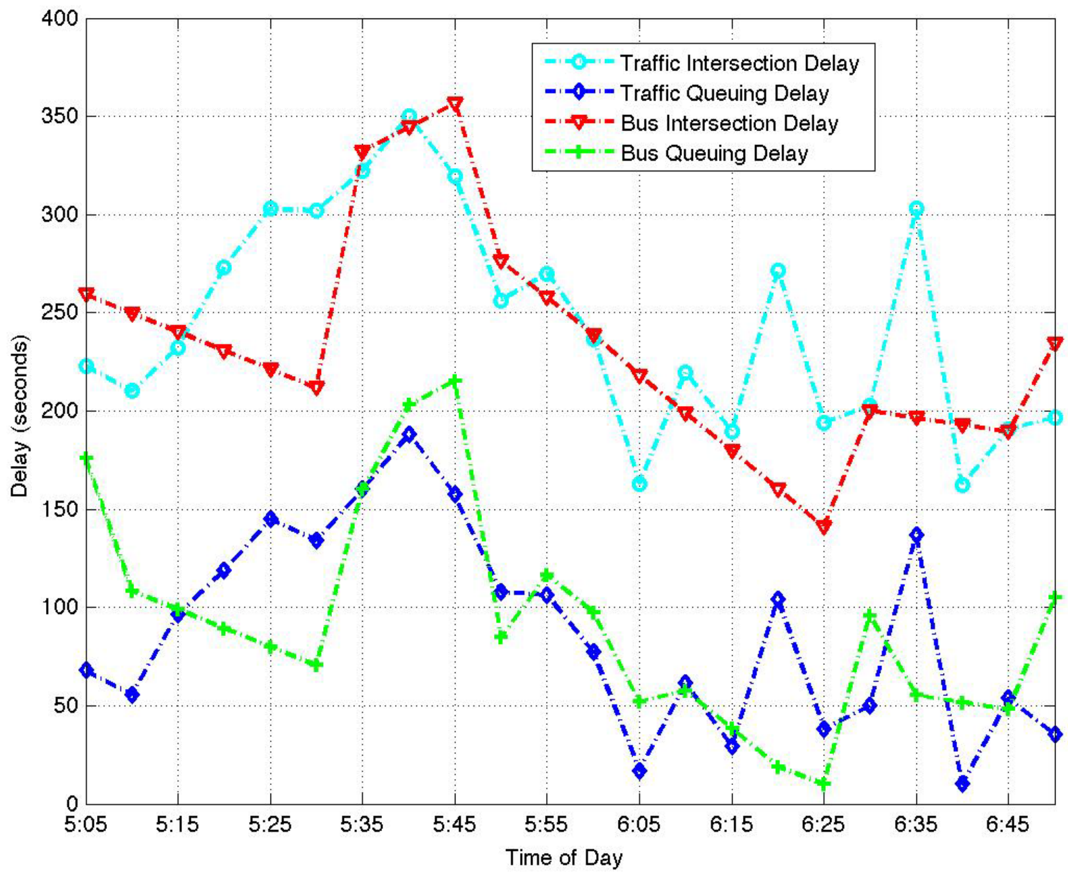


Figure 5-11 Delay comparisons between all traffic and bus probes

The arterial travel time was estimated by using the bus queuing delay plus free flow travel time and the average waiting time at signals for traffic. Figure 5-12 shows two measures of arterial performance: travel time and level of service. For travel time, the curve for estimation results traces the ground truth travel time well. The RMSE of the estimation is 49 seconds and the root mean square percentage error (RMSPE) is just 9%. For the level of service, the estimation model can estimate well the level of service with accuracy rate of 73%. It is noted that the headway of Rapid 522 service is 15 minutes during peak hour and 30 minutes during non-peak time. The model linearly interpolated the results for every five minutes, which led to some deterioration of the model RMSE.

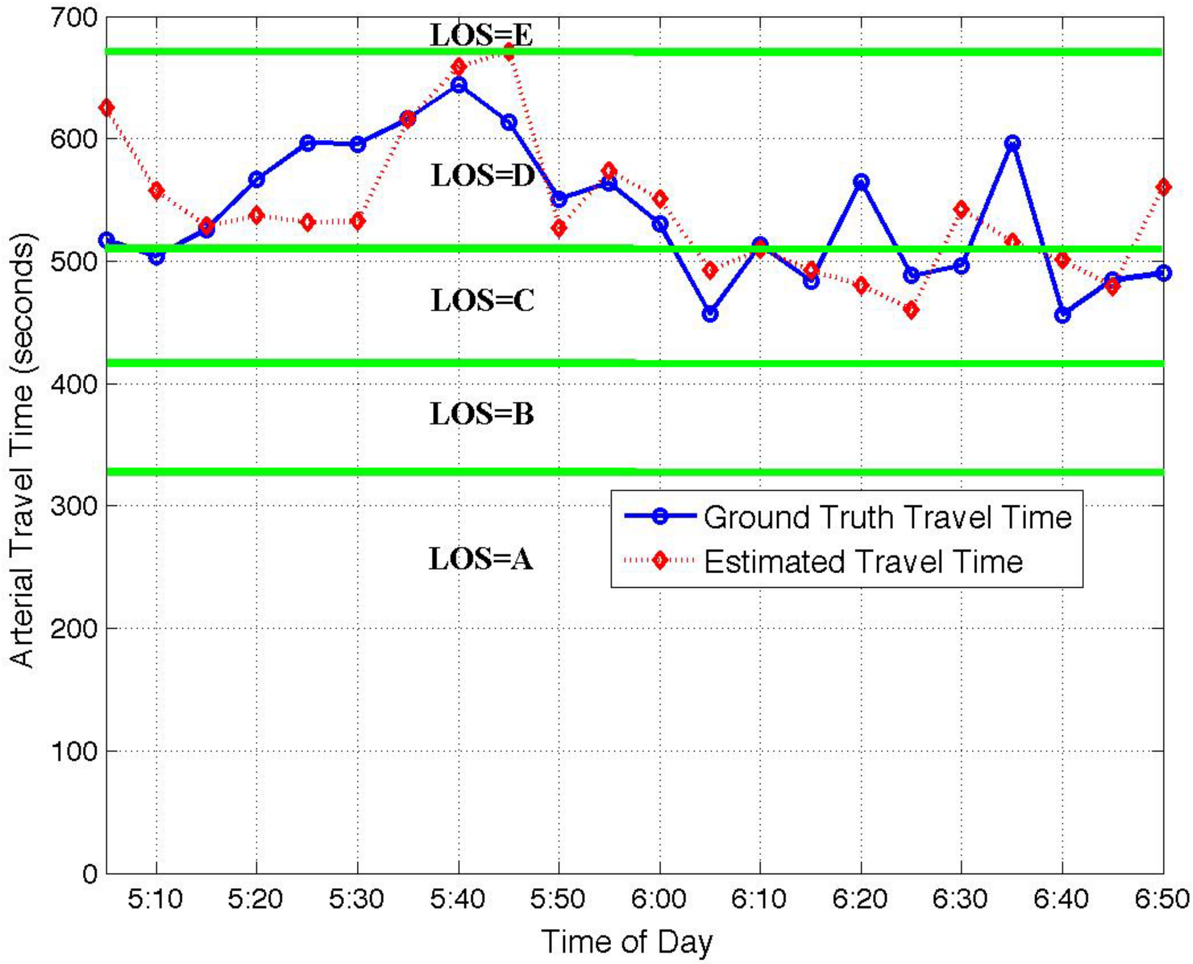


Figure 5-12 Arterial Performance Measurements

5.4.4. Evaluation of real-time parking availability data

Surveyors went to the Caltrain parking lots to manually record the in and out movements of each of the individual vehicles. The manually recorded data are reviewed and compared to the system-generated detection results to evaluate the missed detections and false reports of the parking detection system.

Testing was done between December 20th 2009 to Jan 10th 2010 at Millbrae station and two weeks in March 2009 at the Palo Alto station.

Overall testing results showed that the false reports over the testing period account for 5 samples in over 500 samples, which lead to a false report rate of less than 1%. The number of missed samples for over 500 samples was 11.

The counting error was less than 1.2% (false reports and missed reports averaged out part of the errors).

The overall error rate was less than 3% when the calibration error for overnight counting was also considered.

5.4.5. System Testing of the Geofencing Function

The design allows the system to identify the following scenarios as shown in Table 5-10:

Table 5-10 Identifiable scenarios by Path2go geofencing

Scenarios		Identifiable	Note
Pre-trip	Making a trip plan while driving *vs* Making a trip plan while not driving	Yes √	System uses (1) speed from the GPS data to enable geofencing (G-F) System; (2) Distance of the user from road and bus stop is also taken into consideration while making a decision.
	Making a trip plan while not driving and near a road and bus stop *vs* Making a trip plan while not driving and not near a road and bus stop	Yes √	
	Making a trip plan while riding a bus/train * *vs* Making a trip plan while driving	No ⚠	* In this case system has no prior knowledge of status to distinguish between the two cases and blocks launching of trip planner
En route	User is walking towards train / bus station *vs* User is driving towards train / bus station	Yes √	System uses the (1) saves a state machine tracking the location and speed history of the user; (2) matches the location of the user to the buses / trains, to differentiate the mode.
	User waiting at the bus stop *vs* Pass the bus / train stop while driving	Yes √	
	User is riding the bus / train *vs* User is driving along the bus route	Yes (with constraints)	Trying to mimic the behavior of buses by a car (e.g. stops at a bus stop, or driving on the route following a bus) can cause false fencing.

Due to the limitations of the GPS accuracy and the potential complicated nature of travel, identification of the traveler behavior is subject to error. Different types of errors lead to different consequences. The design of the system therefore aims at minimizing missed detection during driving while keeping the false-blocking rate low.

The performance of the geofencing (G-F) functionality is measured by the successful detection rate of the user driving, versus the false alarms while the user is not driving, given the listed scenarios.

While developing G-F, we identified additional factors that would compromise the usability and the rate of missed detection of usage by drivers. These factors include more than the rate; they include the characteristics of each occurrence of what may be missing.

A. System testing cases of G-F

System field testing was carried out on March 15th and March 24th, 2010. The testing was conducted by two PATH testers traveling the following route:

- Caltrain, then
- VTA 522: Palo Alto, California Ave, Arastradero Ave, Showers Ave, Castro Ave.

A total of 20 trips were made, including 16 en-route trips (where ten trips involved driving and six trips with transit and walking) and 4 pre-trip test cases and are summarized in Table 5-11.

Table 5-11 Test cases of Path2go geofencing

En route		Test cases	G-F result
	Walking toward the bus / train stop then take transit + riding the bus / train	03/15: 11:30 am, walking toward VTA 522 California ECR stop, the take bus to Showers ECR,	did not block √
		03/15 12pm from VTA Showers ECR to California ECR.	did not block √
		03/15 1:20 pm from VTA 522 California ECR to Palo Alto	did not block √
		03/15 2:20 pm from Caltrain California Ave to Caltrain Palo Alto	did not block √
		03/24 1:40pm VTA California ECR to Arastradero ECR	did not block √
		03/24 1:55pm VTA Arastradero ECR to Showers ECR	did not block √
		03/24 2:10pm VTA Showers ECR to California ECR	did not block √
	Driving toward bus / train stop then wait	03/24 2:20pm drove to Caltrain California Ave, planner trip from California Ave to San	Blocked while driving, and did

En route		Test cases	G-F result
	at bus / train stop	Francisco	not block after parked at the parking lot √
		03/15 1:50 pm drove to Caltrain California Ave station, planner trip from California Ave to San Francisco	Same as above √
		03/24 2:46pm drove to Caltrain California Ave, planner trip from California Ave to Mountain View	Same as above √
		03/24 2:50pm Drove from California Ave to Palo Alto train station, parked at the train station. planner trip from Palo Alto to San Francisco	Same as above √
		03/24 3:02 pm Drove from Palo Alto to California ECR, parked at the street parking. Planned trip from California ECR to Showers ECR VTA 522	Same as above √
	Driving toward bus / train stop + driving on the bus route	03/24 3:22 pm Drove from California ECR to Arastradero ECR, drove on bus route then made a U-turn and drive back. Planned trip from Arastradero ECR to Showers ECR VTA 522	Blocked while driving √
		03/15 2:40 pm Drove from California ECR to Showers ECR, drove on toward the bus stop then drove on the bus route. Planned trip from California ECR to Showers ECR 522	Blocked while driving √
		03/24 3:32 pm Drove from Arastradero ECR to Palo Alto, drove on toward the bus stop then drove on the bus route. Planned trip from California ECR to Palo Alto VTA 522	Blocked while driving √
		03/24 3:45 pm Drove from Palo Alto to California Ave, drove on the bus route. Planned trip from California ECR to Palo Alto VTA 522 A bus was following our car.	Blocked at first. Then started showing information ⚠
Pre trip			
	Making a trip plan	03/24 11:30 am Making a trip plan from Bldg.	Did not block

En route	Test cases	G-F result
some distance from a road and bus stop, while not driving and	180 at RFS	√
Making a trip plan near a road and bus stop, while not driving	03/24 12:40 pm Making a trip plan from a stationary position at Central Ave off 580	Did not block √
Making a trip plan while driving	03/24 12:45 pm Making a trip plan while driving from Central Ave off 580 to ECR in South Bay	Blocked √
Making a trip plan while riding a bus/train	03/24 2:15pm VTA Showers ECR to California ECR	Blocked ⚠
Total	**En route**: 6 walking + transit cases: all ok, 10 involved driving, 9 were successful. One failed because a bus for the planned route was following the car. **Pre-trip**: 4 different scenarios, 3 were successful, 1 failed as the system did not have enough information if the user was driving or taking transit.	

The geofencing system testing showed that the functionality of the geofencing satisfied the requirement of the Path2go system design.

5.5. Outreach and Rolling out of Path2go

5.5.1. Overview of outreaching efforts

Major outreaching efforts of the Path2go FOT included:

- Working with local transportation agencies to connect with their customers,
- Linking to the project website from the 511.org website (see Figure. F-2 and Figure. F-3);
- Distributing press releases by UC Berkeley ITS;
- Distributing flyers at Caltrain stations ; (see Figure. F-1 for the flyer design)
- Using social networking media (Facebook and Twitter).

Table 5-12 below summarizes the major media coverage for the networked traveler project's FOT.

Table 5-12 Media coverage after the press release (table courtesy of the independent evaluator's report)

Date	Activity	Notes
29-Jul-10	Targeted Marketing	PATH2Go applications advertised on MTC's 511 website (www.511.org). Displayed on homepage for 4-5 weeks.
8-Aug-10	Media Coverage	Mass Transit blog - http://www.masstransitmag.com/interactive/2010/08/05/there%E2%80%99s-an-app-for-that/
31-Aug-10	Targeted Marketing	Press release launched by UC Berkeley Institute of Transportation Studies (ITS) - http://its.berkeley.edu/about
31-Aug-10	Media Coverage	UC Berkeley News Center - http://newscenter.berkeley.edu
31-Aug-10	Media Coverage	Transportation Communications Newsletter - blog post - http://transport-communications.blogspot.com/2010/08/tuesday-august-31-2010.html
1-Sep-10	Targeted marketing	Distribution of flyers at transit stations - the PATH team handed out flyers 2 times or more per week from the beginning of September into early October.
1-Sep-10	Media Coverage	Traffic Technology Today blog - http://www.traffictechnologytoday.com/news.php?NewsID=24390
2-Sep-10	Media Coverage	UC Berkeley - Daily Californian web article (Student-run Newspaper) - http://www.dailycal.org/article/110191/uc_berkeley_researchers_launch_new_trip-planning_p
2-Sep-10	Media Coverage	The Transit Wire blog - http://www.thetransitwire.com/2010/09/02/researchers-to-test-impacts-of-traveler-info/
3-Sep-10	Media Coverage	AASHTO Journal Online - Weekly Transportation Report - http://www.aashtojournal.org/Pages/090310california.aspx
6-Sep-10	Test Launch Date	Android application released into Google Android Marketplace - http://www.android.com/market/#app=basesign.alltie
15-Sep-10	Targeted Marketing	Tweet on *caltrain* Twitter Account – 4,997 followers as of 11/17/2010 – http://twitter.com/#!/caltrain
7-Oct-10	Media Coverage	SF Examiner article - Local Section of Web - http://www.sfexaminer.com/local/Muni-working-on-app-for-smart-phone-users-104469069.html

5.5.2. Rolling Out Path2go

Path2go was rolled out on July 27th 2010.

The FOT's duration was from July 27th 2010 to November 15th 2010.

As of November 15th 2010, the Path2go application attracted over 1800 users, among which there were over 600 mobile phone users.

5.5.3. Support for Independent Evaluation

The PATH project team provided extensive support for the independent evaluators as listed below:

- Develop the post-account-creation-survey to collect user information for the independent evaluation; the survey was designed based on input from the evaluator;
- Develop the automatic popup box to remind users about the survey administered by the independent evaluators.
- Send invitation emails to the participants to take the survey administered by the independent evaluators;
- Support for the geofencing testing; providing documents to explain the geofencing logic;

5.6. FOT Data Analysis

5.6.1. Background of Users and Usage Type Analysis

The data from the various sources have been collected by two facilities at the California PATH research center: web user data as well as mobile requests for transit arrival times are stored in the frontend web server; other types of mobile user data and mobile trip planning requests are stored in the backend mobile server, as depicted in the following diagram (Figure 5-13):

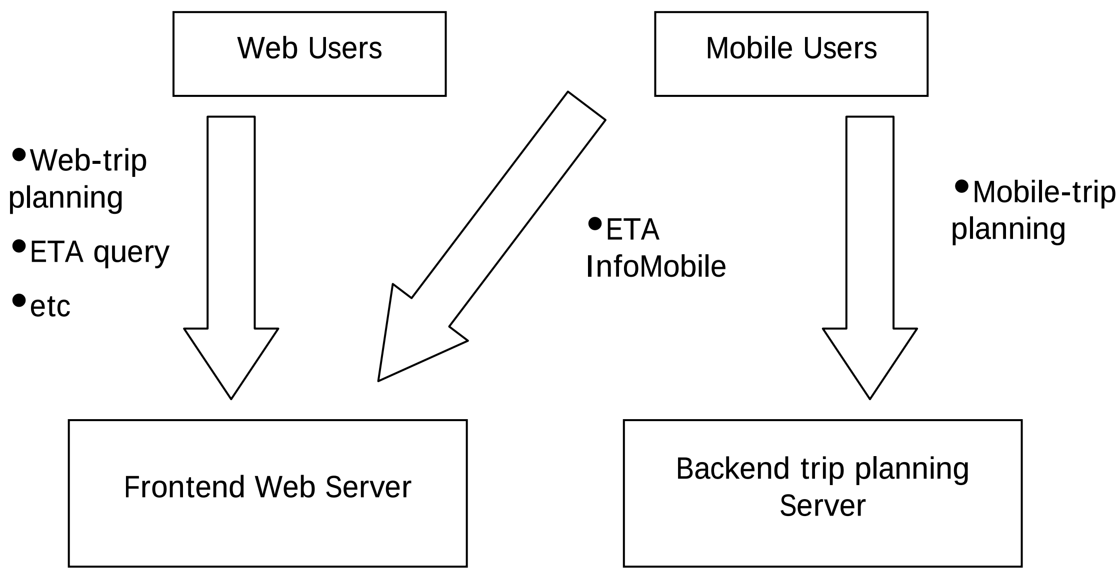


Figure 5-13. Data Configuration

The project team conducted an analysis of the server records logged by the Path2go system. This analysis aimed at learning how the users used the system.

In Table 5-13, different usage types that are recorded by Path2go servers are listed. The records of those data are the basis for the analysis.

Table 5-13 Different Usage Types of Path2go

Usage Type	Platform	Query type	Registered or anonymous
TripPlanner	Web	Trip planning request from web users	Both
RouteInfo	Web	Request of transit route information via web	Both
ETATripInfo	Web	Real-time update of ETA (estimated time to arrival) of a planned trip via web	Both
Search	Web	Search for real-time transit information using keyword searching	Both
ETATimeInfo	Web	Checking the ETA time of a particular route at a stop	Both
ETAInfoMobile	Mobile	Checking the ETA time of a particular route at a stop using cell phone	Registered users only
CheckActive	Mobile	Request sent by the mobile phone when the application is first launched	Registered users only
PostGPSArray	Mobile	Realtime update of the trip via mobile phone	Registered users only
TripPlannerServer	Mobile	Trip planning request on mobile phone	Registered users only

In order to generate meaningful results, several units of analysis were specified:

- Clicks: Under this unit of analysis, the raw data is not filtered. Thus, every request from a user counts as a separate entry.
- Sessions: This unit of analysis filters the data into separate sessions. Specifically, data entries which are of the same user, same IP address, same usage type, and is recorded within the last 600 seconds of the previous record are counted as duplicates and are therefore removed.
- Users: This unit of analysis aims to gather information about the number of users and their respective usage types, regardless of their usage frequencies. Thus, entries of data which are from the same user and same usage type are considered as duplicates and removed.

5.6.2. Users

The information about users is collected from the post-account creation survey, details of which are shown in Appendix B.

Survey respondents were asked to provide general information such as their income, commute distance, trip duration, and their modes of travel. Two hundred forty-four surveys were received and the distributions of the respondents' demographics and usage types are shown in this section.

Figure 5-14 shows the income groups of the respondents.

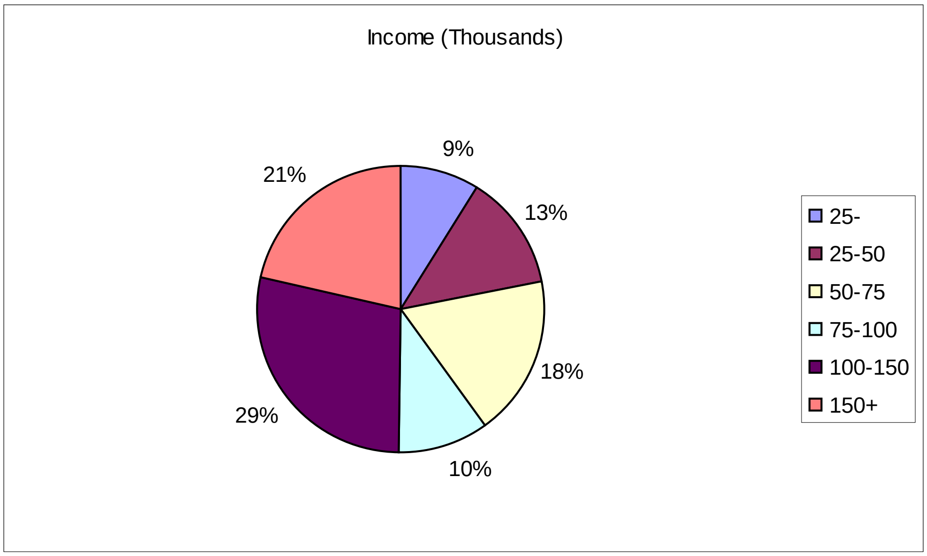


Figure 5-14 Statistics of income group of respondents

As shown, the majority of the respondents belong to the group commonly referred to as the "upper middle class", with half of them having annual incomes of over $100,000. It is also expected that most of the respondents are full-time workers of at least mid-career level, as opposed to being college students or new graduates.

Respondents were also asked to indicate their commute distance in miles.

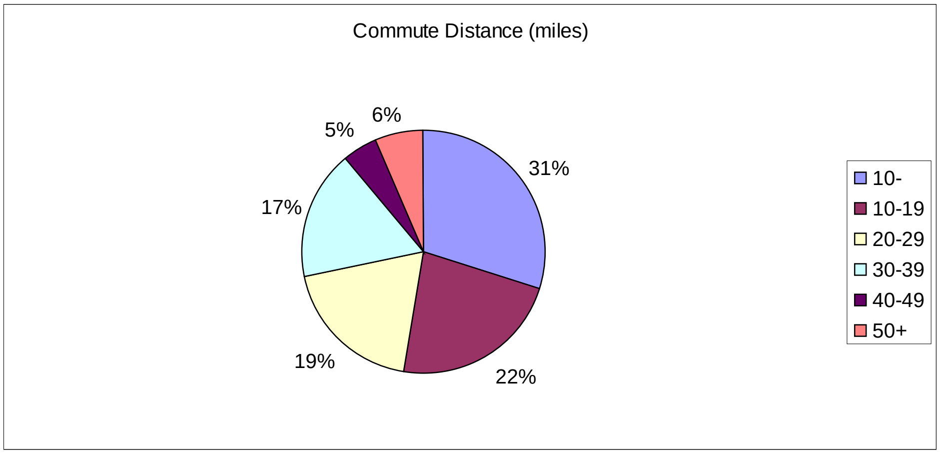


Figure 5-15 Statistics of commute distance of respondents

As indicated by Figure 5-15, there is a diversified distribution of commute distance of the subjects' work trips. While 53% of the group lives within 20 miles of their workplace, 28% of the commute trips are over 30 miles.

Respondents were asked to indicate the duration of the average commute trip. The commute trip duration distribution of the subjects is shown in Figure 5-16:

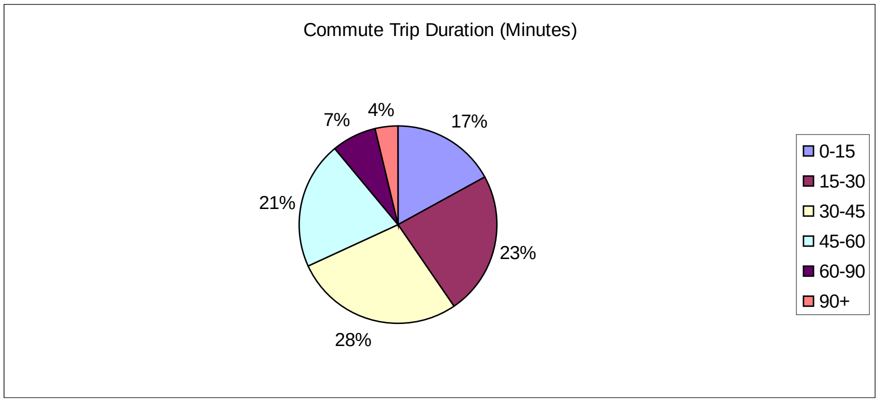


Figure 5-16 Statistics of commute time of respondents

As shown Figure 5-16, close to three quarters of the commute trips have durations of less than 45 minutes; while more than 11% of the subjects have commute trips of more than one hour.

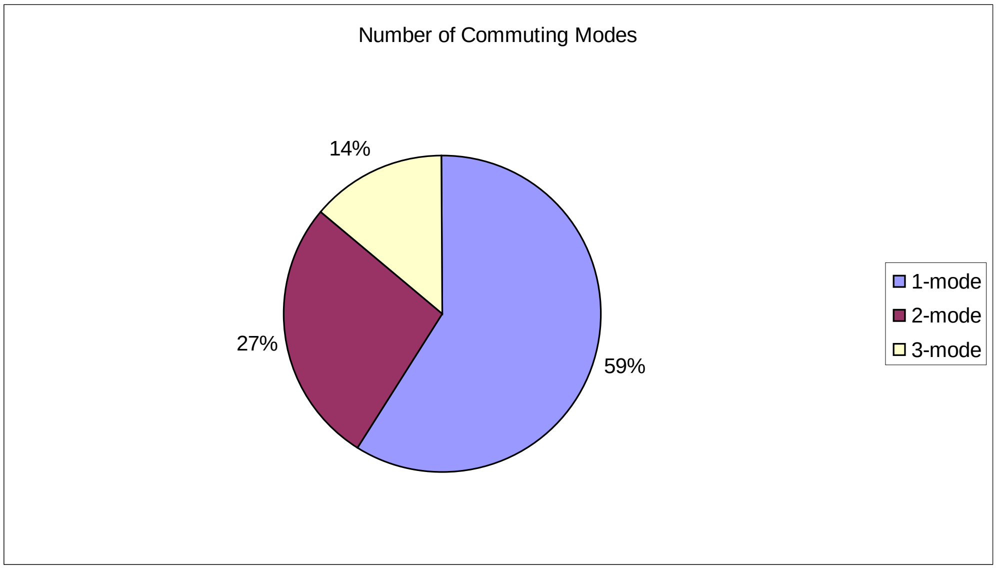


Figure 5-17 Statistics of number of the commute modes of respondents

Figure 5-17 shows that approximately 59% of the respondents indicated that they have only one mode of commuting, while 27% of them choose between two alternatives. In addition, 14% of them use up to three different commuting modes.

Figure 5-18 shows the percentages of the subjects who travel with certain modes:

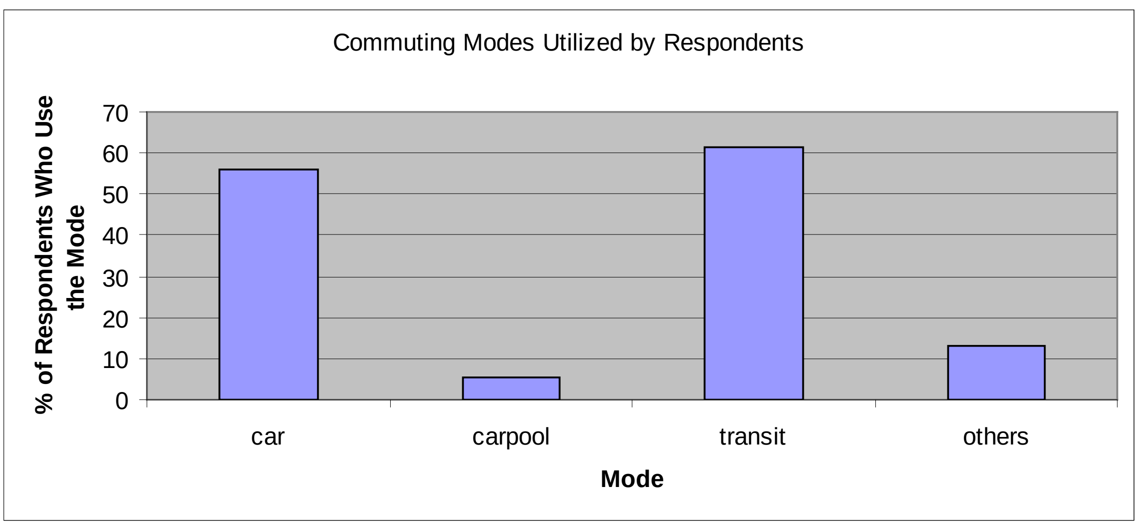


Figure 5-18 Percentage of respondents for each commute mode

Note that the above figure indicates the percentage of subjects who include the depicted mode choices into their commute alternatives. For example, approximately 56% of the subjects include driving alone as a possible (but not necessarily the only) commuting mode choice. As shown, over 60% of the subjects consider transit as at least one of their feasible mode choices, followed closely by their personal vehicle. Carpooling and other modal types such as walking or biking are deemed favorable to less than 15% of the respondents.

Subjects were also asked to indicate their sources of traffic and transit information. Figure 5-19 below shows the distribution of the number of information sources used by the subjects:

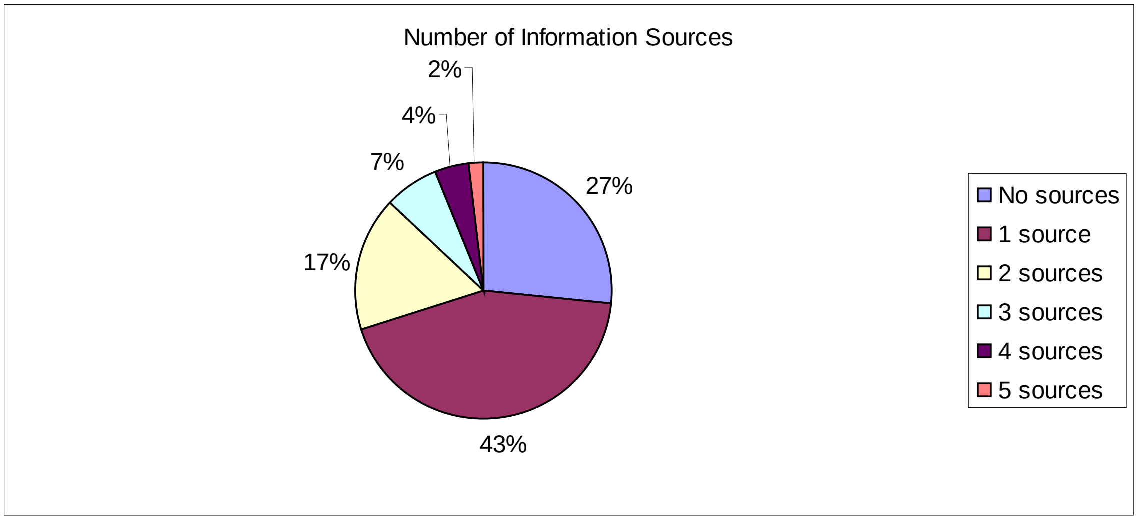


Figure 5-19 Distribution of number of information sources

As indicated Figure 5-19, slightly more than one quarter of the subjects do not attempt to obtain real time traffic information, while about 43% of the subjects utilize one information source. Thirty percent of the subjects utilize two or more sources of information.

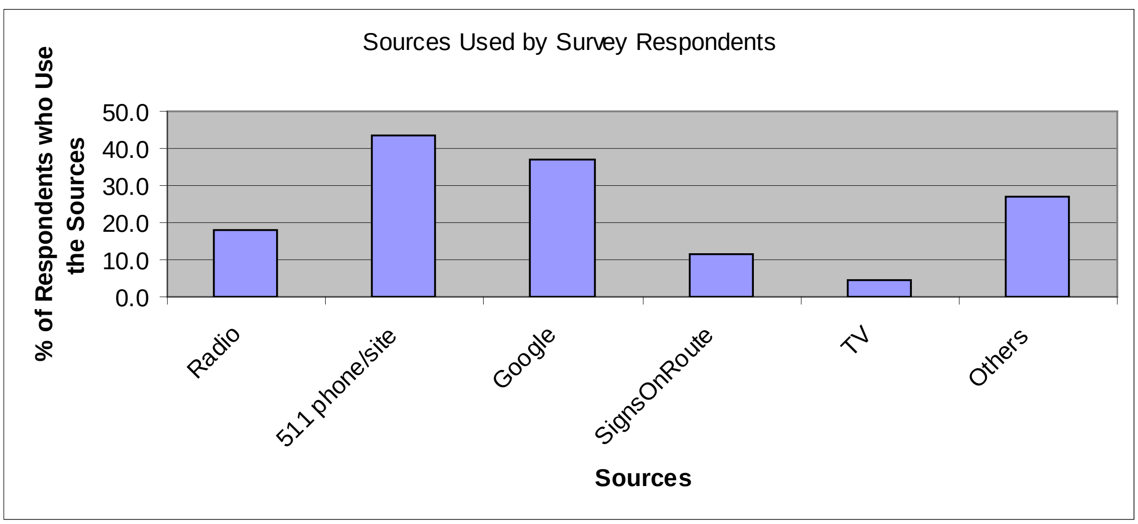


Figure 5-20 Traveler information sources

Figure 5-20 above shows that 511 services are the most popular type of information source among the subject group, with over 40% of the subjects utilizing them. They are closely followed by Google. In addition, a significant amount of respondents (close to 30%) indicate that they consult other sources of information such as other mobile phone applications or websites.

5.6.3. Usage statistics

There are a total of 1,878 unique users of the networked traveler project services. As seen from Figure 5-21, the majority of them are web users.

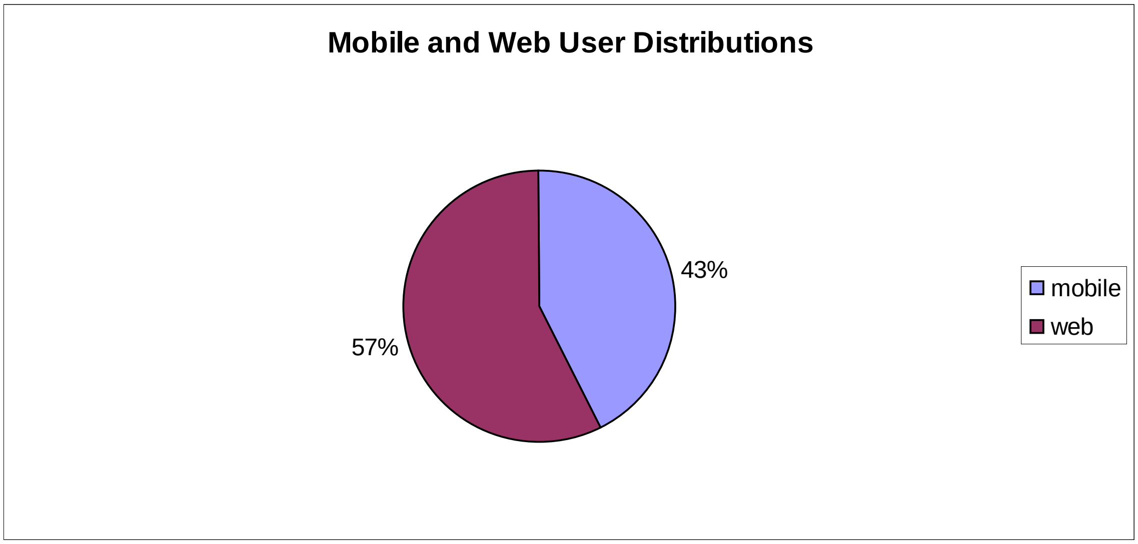
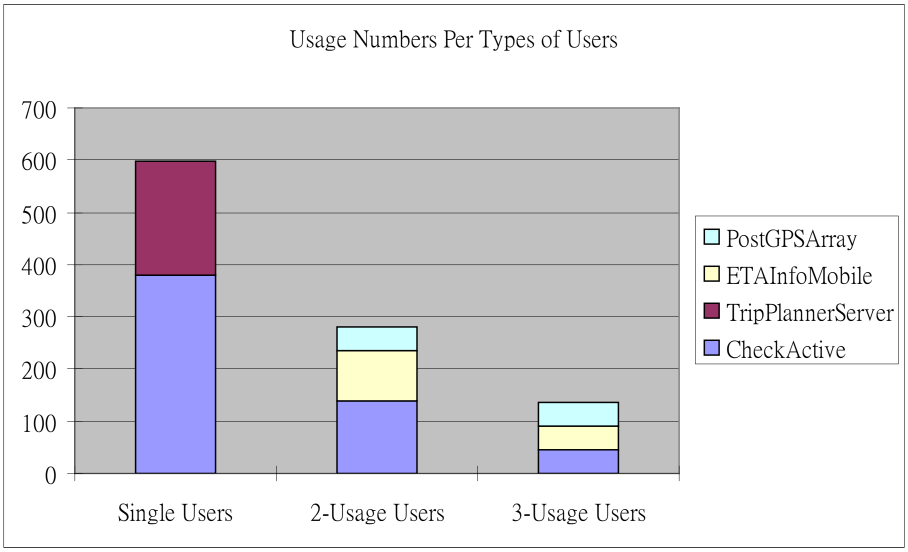


Figure 5-21 User Type Distributions

Since it is useful to determine the number of users of the networked traveler project services, the following results were obtained about usage types. There are a total of 783 mobile users, and their usage types are shown in Figure 5-22.



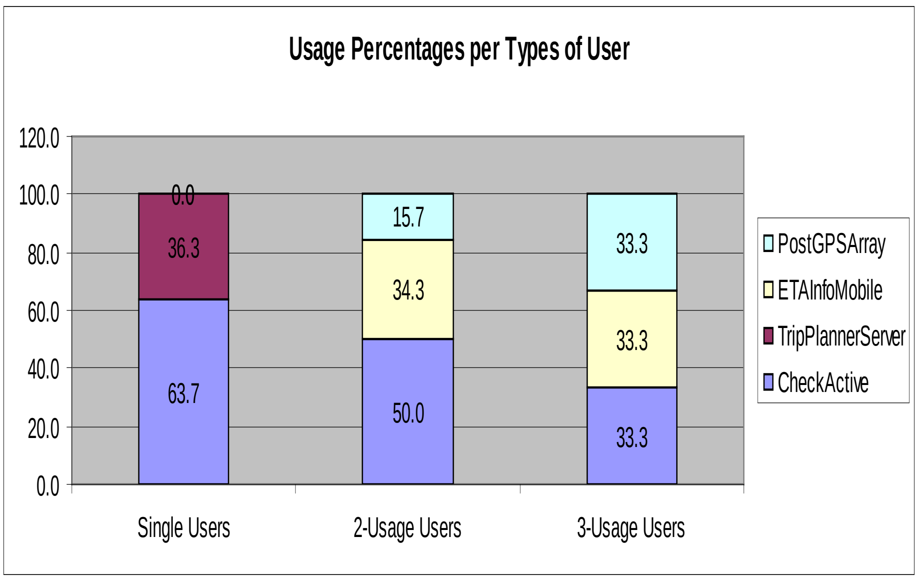


Figure 5-22 Usage Numbers and Percentages Per Types of Mobile Users

There are 598 single-usage-type users, 140 2-usage-type users, and 45 3-usage-type users. Since the usage type "CheckActive" is automatically recorded whenever a user activates his or her mobile application, this usage type is always present (except for data type "TripPlannerServer", where data is recorded in the backend mobile server). The vast majority of the mobile users are single usage users, and the majority of them only generate the usage type CheckActive. In other words, they did not use the application for any specific purpose. A possible reason is that they were not interested in the application after activating it for the first time. As CheckActive is always activated, it is always one of the two usage types of the 2-usage users. The other usage types are ETAInfoMobile and PostGPSArray. The 3-usage-type users, by definition, must use all 3 typesand each of the three types of usage constitutes one third of the total usage of the 3-usage-type users.

It is also possible to determine the type of smartphones used by the users who made mobile TripPlannerServer requests (Figure 5-23). Thus, a total of 489 smartphone data entries were recorded:

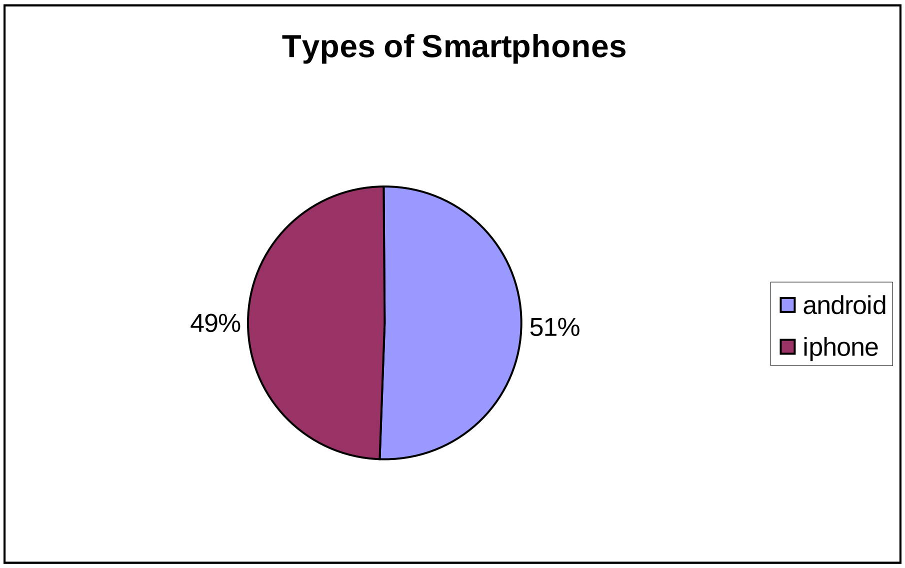
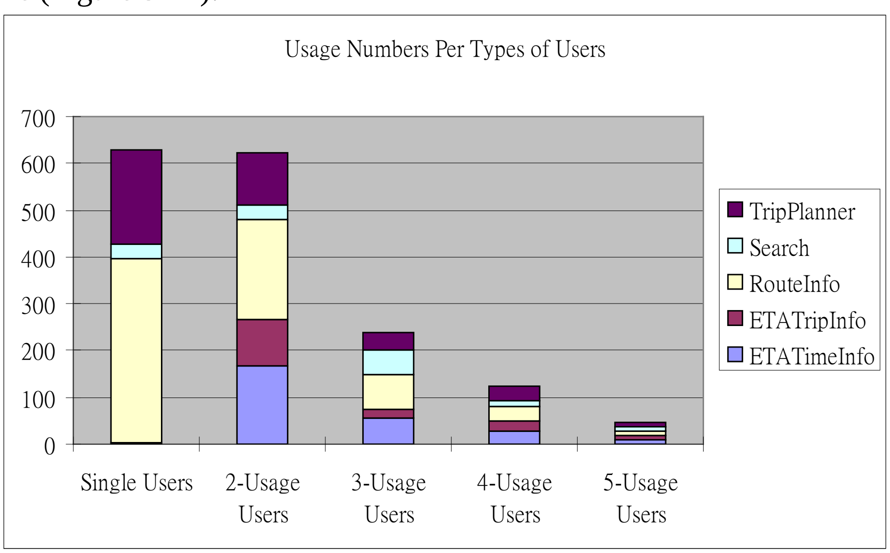


Figure 5-23. Smartphone Types

As shown in the above figure, approximately half of the users possess i-phones, while the other half possess Androids.

In addition, there are a total of 1,059 web users, and their usage types are shown in the following figure (Figure 5-24):



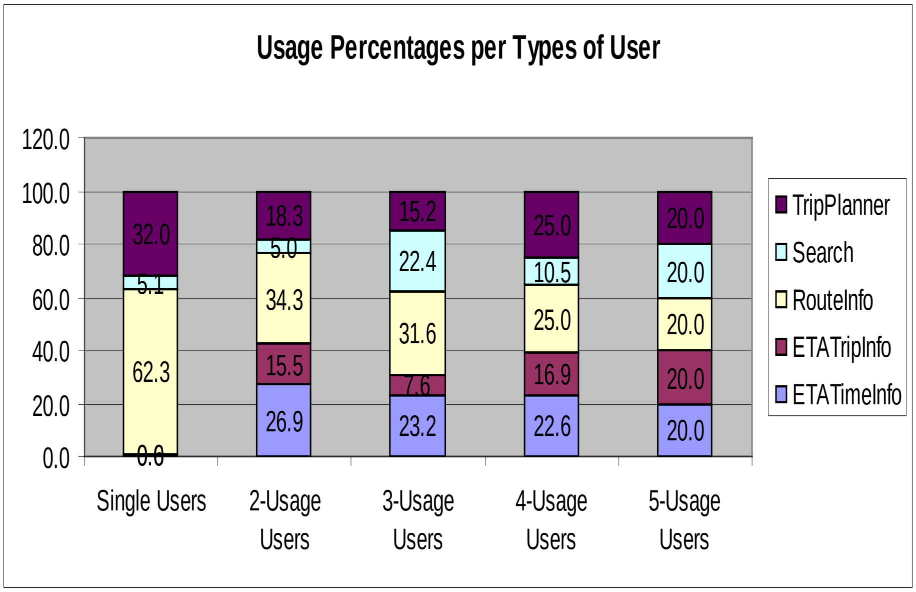


Figure 5-24 Usage Numbers and Percentages per Types of Web Users

There are 628 single-usage-type users, 312 2-usage-type users, 79 3-usage-type users, 31 4-usage-type users, and 9 5-usage-type users. As seen from the figures above, more than half of the users are single-usage-type users, with the majority of them seeking RouteInfo or TripPlanner information. The other user types constitute the majority of the users, with a significant amount of them requesting TripPlanner, RouteInfo, ETATripInfo and ETATimeInfo data types.

5.6.4. Analysis of usage data by usage type

A. Trip planning requests

When a user is inquiring with the TripPlanner usage type, he or she makes a request of one or more of three possible modes:

- Mode 1: Driving
- Mode 2: Transit
- Mode 3: Driving then transit

The following diagram (Figure 5-25) shows the percentages of the requests for each mode:

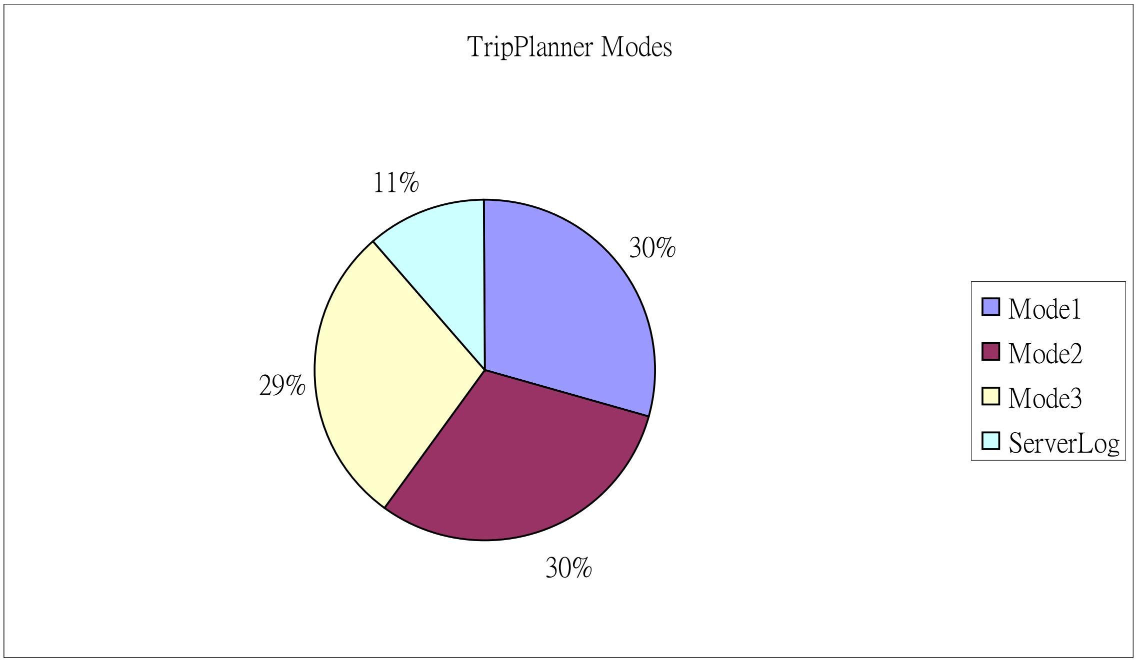


Figure 5-25. TripPlanner Modes Analysis (ServerLog indicates data from mobile users, all for mode 2)

It can be seen that the amount of requests for all three modes are almost equal to each other. A possible reason for this is that unless the user specifies a mode, the "compare modes" button is checked by default and results for all three mode types are generated. In addition, 11% of the total TripPlanner requests come from mobile users, and the mobile application only generates requests for mode 2 (transit).

Every TripPlanner request includes a set of GPS coordinates for the origin and destination of the user's choice. The coordinates can be used to determine the zip code of the locations, and thus the cities/areas of the user's origin and destination. By aggregating the information, it is possible to determine the distribution of cities of user origins and destinations.

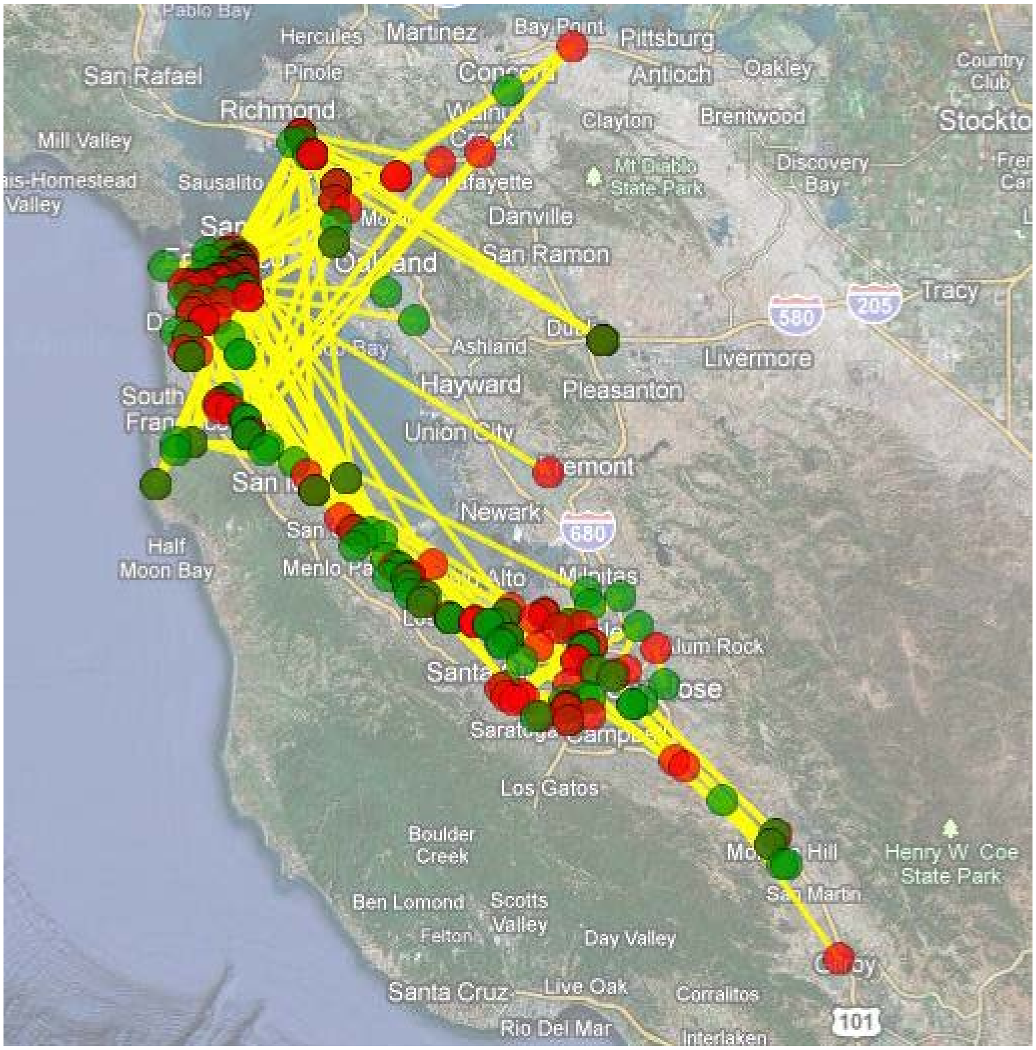
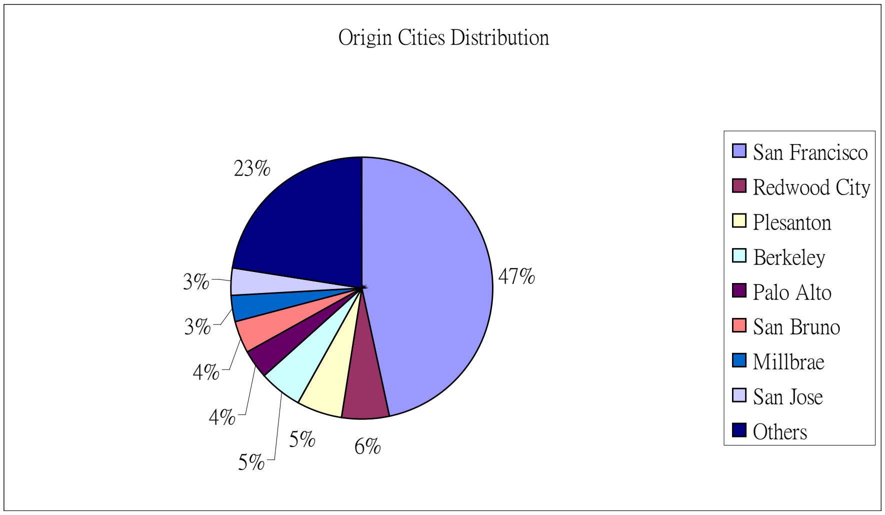


Figure 5-26 Origin and destination pairs of trip planning requests (Red dot: origin, green dot: destination)

Figure 5-26 visualizes the O-D pairs on a Google map. The visualization tool used was gpsvisualizer.com.



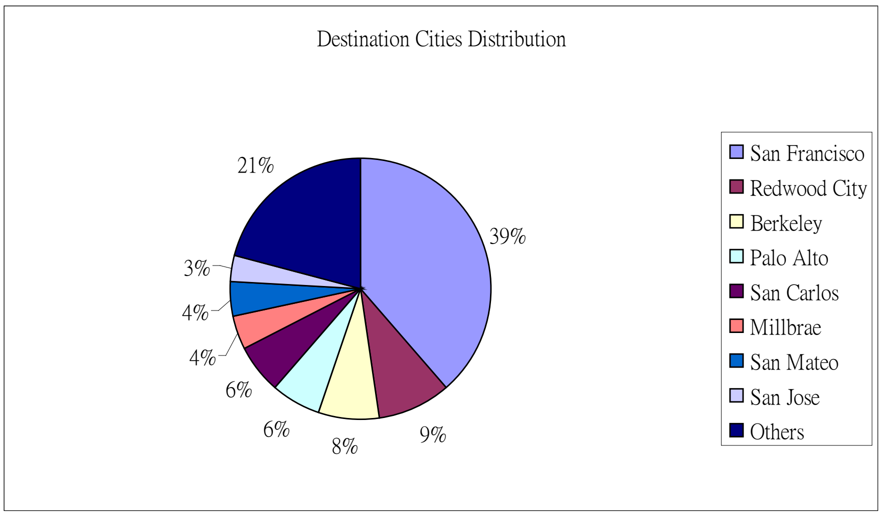


Figure 5-27 Trip Planner Origins and Destinations Distribution

As shown above in Figure 5-27, San Francisco is the city at which most trips begin and end. The next few cities in rank are mainly Redwood City, Berkeley, Palo Alto, Millbrae, and San Jose in both cases. It can be seen that Pleasanton accounts for about 5% of all the origin points, but less than 3% of the destinations. If origins are generally the residential areas of the users, it can be inferred that Pleasanton is a residential zone rather than a work zone. The opposite can be said for San Carlos, which accounts for 6% of the destinations but less than 3% of the origins.

B. Estimated Time of Arrival (ETA)

A total number of 1,837 requests for transit arrival times were made on the web and with smart phones; their distribution is shown below in Figure 5-28:

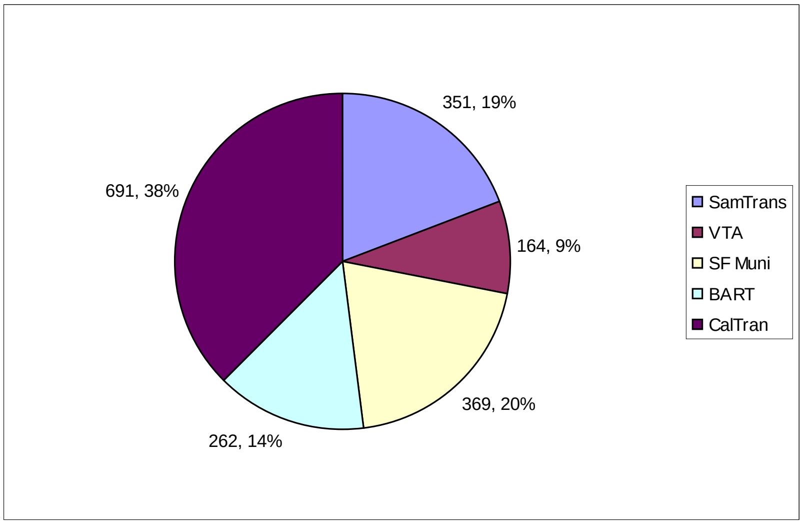


Figure 5-28. Numbers of ETA Information Request by Agencies

As shown in Figure 5-28 above, the transit agency whose arrival times are requested the most is Caltrain, accounting for 38% of the total number of requests. The second most requested agency is SF Muni, closely followed by SamTrans and BART. The least requested agency is VTA, which accounts for only 9% of the total requests.

C. Distribution of different kind of inquiries

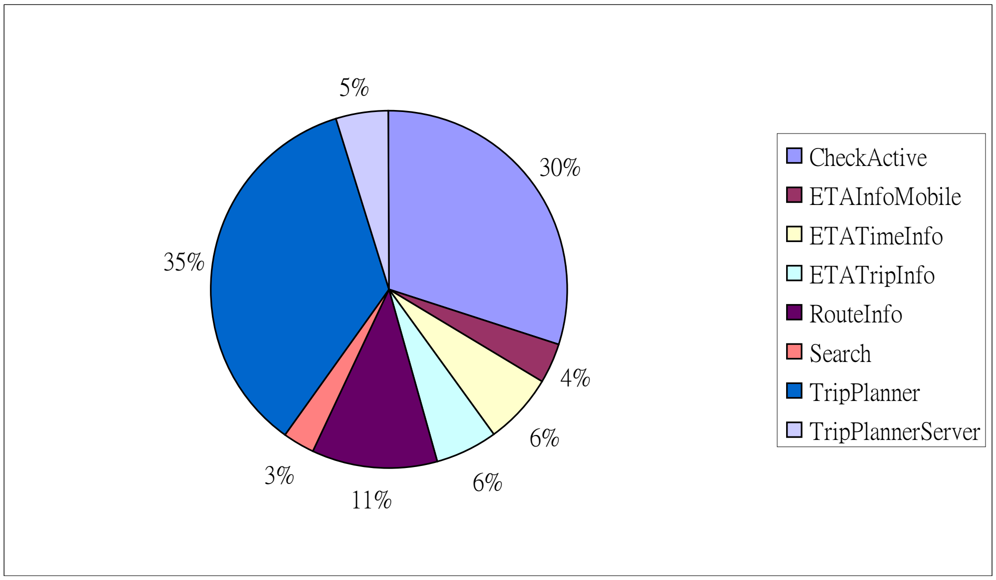


Figure 5-29. Total Inquiries by Type

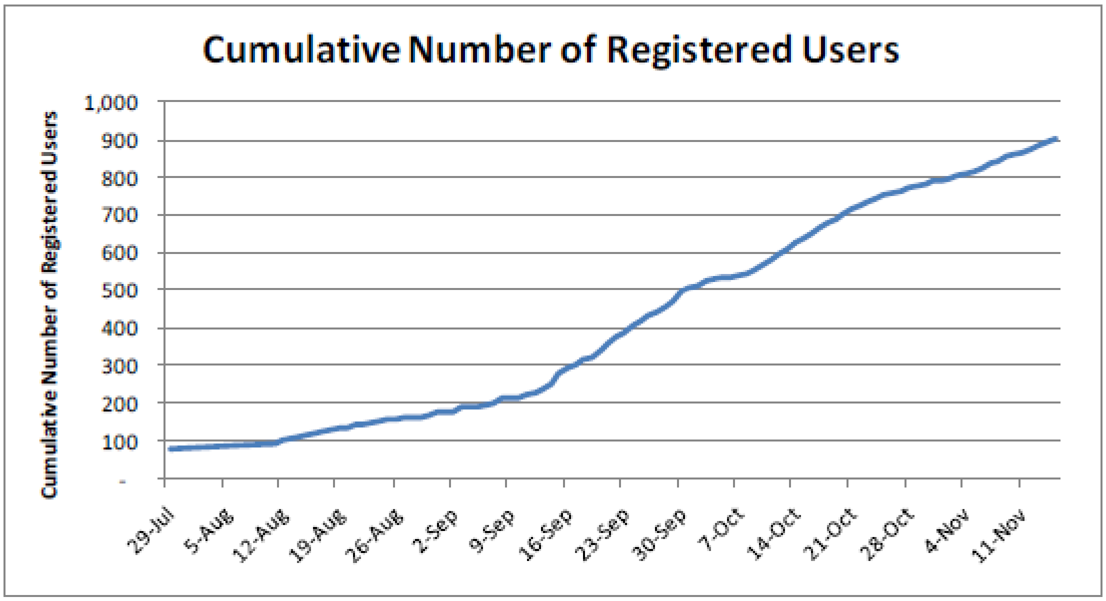
The distribution of all web and mobile request types has been conducted. As seen from Figure 5-29 above, the most requested information type is TripPlanner that accounts for 35% of the total requests. Since CheckActive is actually not a type of user request, the next most requested type is RouteInfo, followed by ETA information lookups.

5.6.5. Usage Patterns

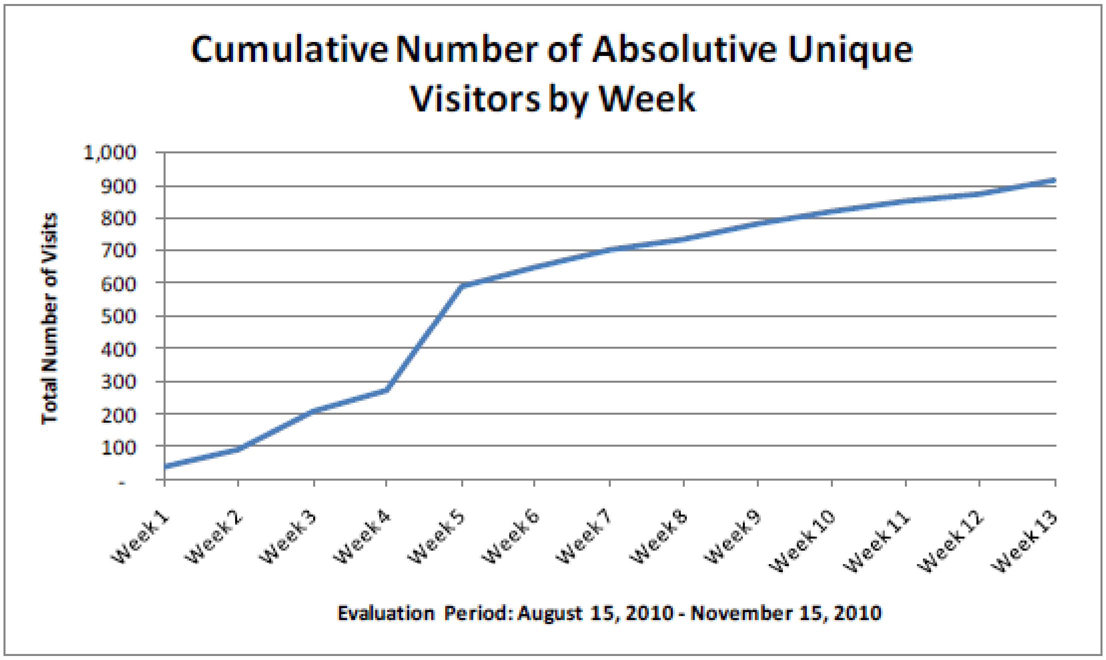
It is also of interest to study usage patterns because such data is helpful in understanding the performance of the system.

A. Growth of Number of Users and Visits

Steady growth of both cumulative number of registered users (for both mobile applications and web application) and the cumulative web visits were seen during the FOT. Figure 5-30 illustrates these two cumulative numbers. The data source for registered users is the Path2go server log while the data source for the web visits is the Google Analytics results.



(a) Cumulative Number of Registered Users, July 29, 2010 – November 15, 2010 (Courtesy of the independent evaluation report)



(b) Cumulative Number of Absolute Unique Visitors by Week, August 2010 – November 15, 2010 (Courtesy of independent evaluation report)

Figure 5-30 Cumulative Number of Users and Visits

B. Visits and New Visits to the Path2go Server

Based on the Google Analytics results, we also obtained the day-to-day variation of two metrics echoing how the users employed the application: (1) number of visits to Path2go (Web application only) ; and (2) percentage of new visits.

The two metrics are plotted together in the figure below by Google Analytics.

(1) There is a peak in the number of visits on the week of September 7th, 2010, which is caused by a post on the @Caltrain twitter, which had over 4,000 followers at the time. This peak also demonstrated that the new social media worked most effectively in marketing the application.

(2) Fluctuation can be seen on the daily usage and number of visits. This is partly because of relatively small number of user basis;

(3) Average we see returning visits accounted for more than 50%. From time to time, the new visits can take more than 50%, but those days were usually when number of visits was also low.

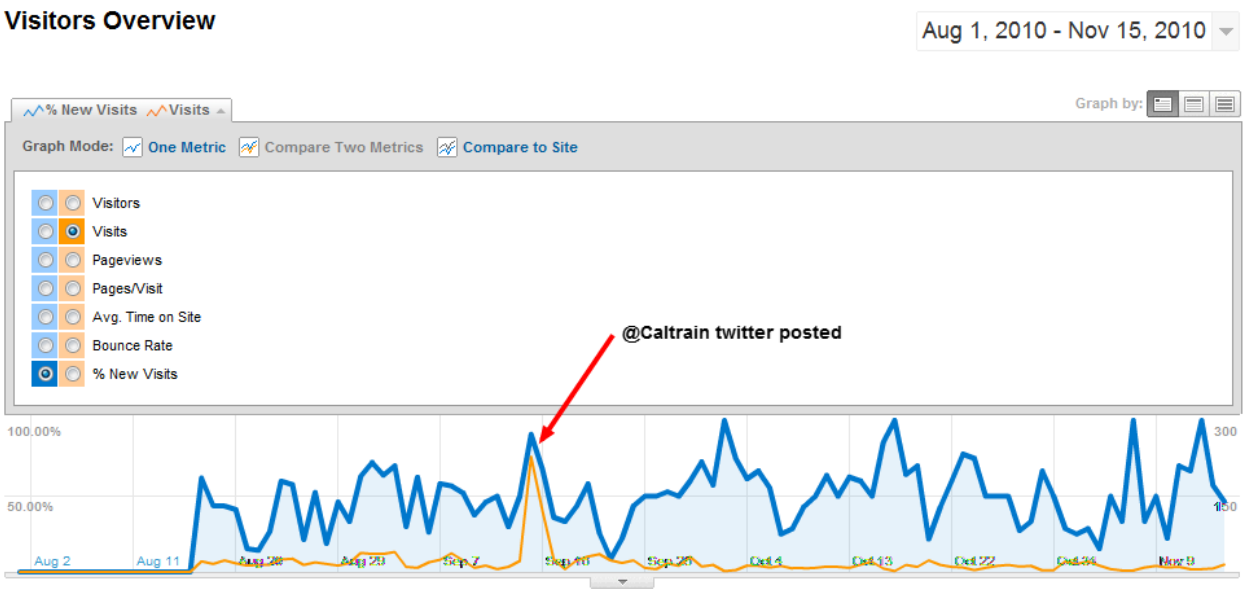


Figure 5-31 Google Analytics Result: Number of visits and percentage of new visits per day, August 2010 – November 15, 2010

C. Page Visit of the Web application

We use the time on site as the major metric. Another usually employed metric, the number of page views per visit, does not apply here simply because the trip planner application is implemented as a javascript-based single-page website. Figure 5-32 shows the result for the FOT period.

The average time on site is 2 minutes 12 seconds per visit.

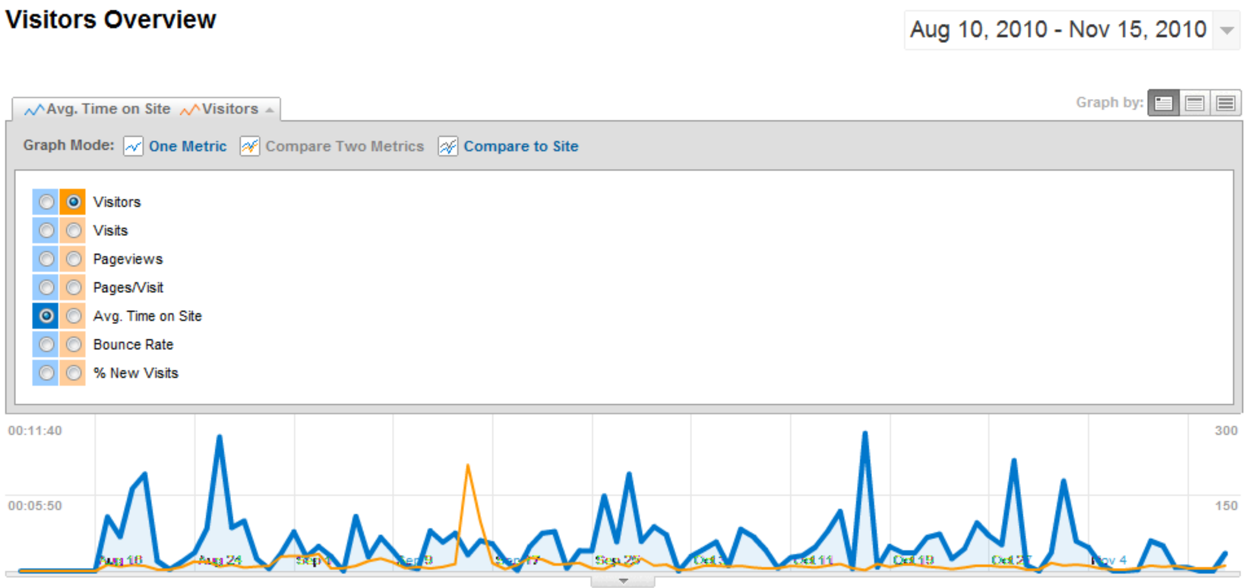


Figure 5-32 Google Analytics Result of the average time on site and number of visitors per day, August, 2010-November 15, 2010

D. Average Time of Mobile Phone Usage

On the Path2go server, there is no mechanism to learn the average time a mobile phone user used the mobile application. However there is a automatic update function of the mobile application that posts an API call to the Path2go server periodically for trip information updates. That API is called PostGPSArray. The server record of consecutive calls to that API can be used as one metric for the mobile phone usage pattern.

PostGPSArray requests are sent to the frontend web server continually as long as a Smartphone user is using the Path2go mobile application. The duration of PostGPSArray requests of each user gives information on how long the user spends on the application when he or she is using it (Figure 5-33).

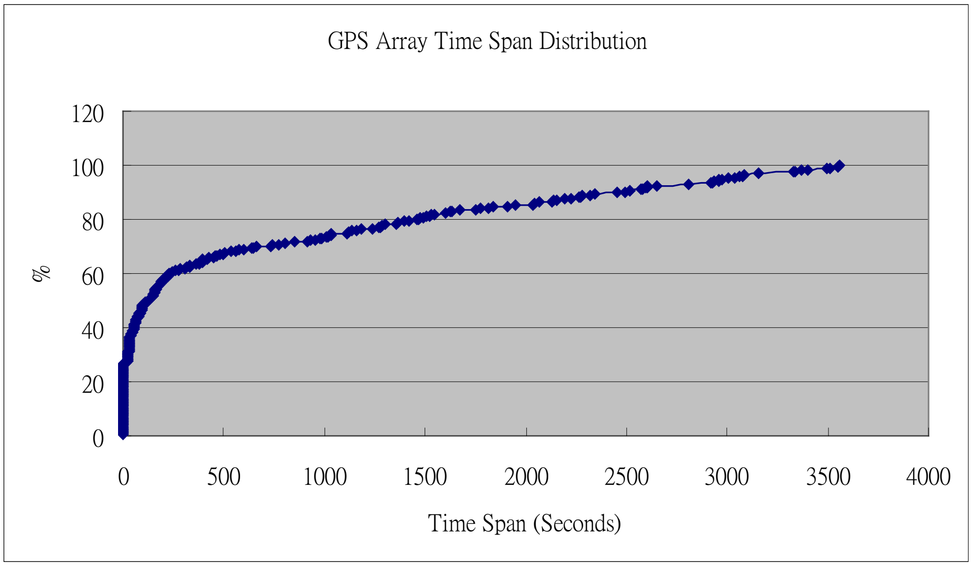
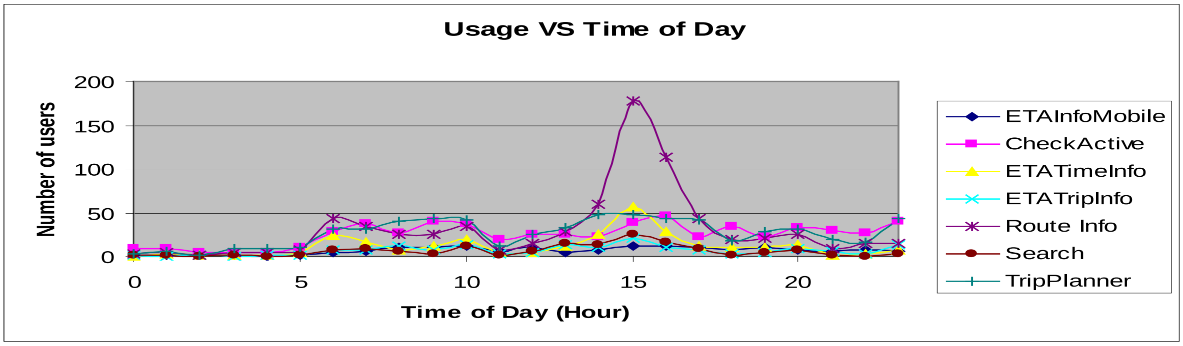


Figure 5-33. PostGPSArray Time Span Distribution

As shown above approximately 50% of the users stay with the application for less than 2 minutes. However, the 80th percentile of the data is at about 25 minutes. Time intervals of over one hour are discarded, since it is assumed that the users simply forgot to turn off the application in those cases.

E. Time-of-day Pattern of Usage

The time-of-day usage pattern is shown in Figure 5-34. It is expected that information requests are more numerous during peak hours, when traffic is worse in general.



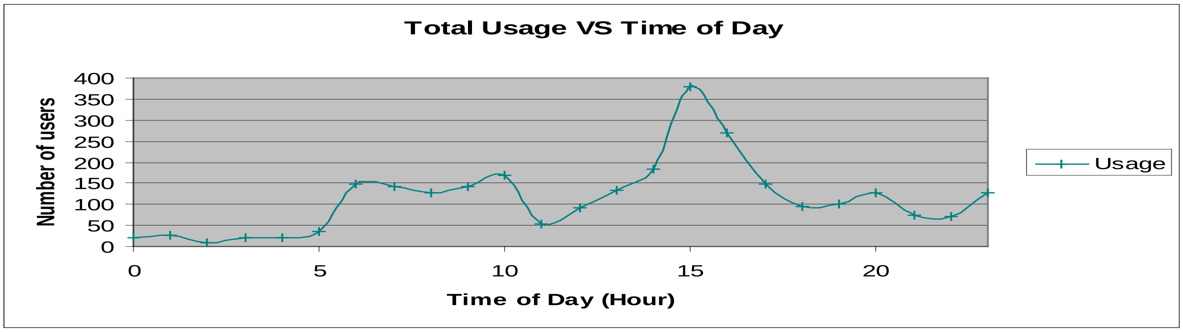


Figure 5-34 Usage Data During Different Times of the Day

The findings above in Figure 5-34 show that the usage data is consistent with the prediction that more users make requests during the busier times of the day: The number of total users starts increasing at approximately 6 AM, shortly before the AM peak. The RouteInfo requests feature an extreme case, with a peak of about 175 users centered at 3 PM, more than 3 times the number of users of the second highest peak at 6 AM. The number of requests is lowest from 12-5AM, consistent with the sleeping patterns of the general public.

5.6.6. Comparison of Server Data Analysis with Google Analytics Results

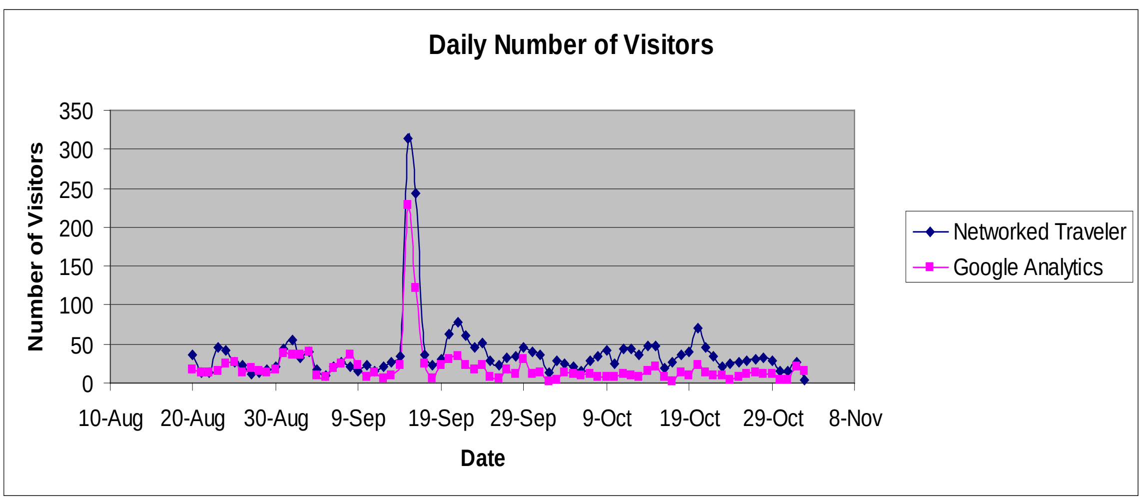


Figure 5-35 Comparison with Google Analytics

In Figure 5-35above, the daily number of visitors of the Networked Traveler resources and Google Analytics are plotted against the days of the study period. As shown in the figure, the overall patterns of the two curves are quite similar. It is also worthwhile to note that both information sources experience the same request peak on 15th - 16th September (when a twitter message was posted to @caltrain which haD 4,900+ followers). This shows that the Networked Traveler Project is able to obtain users who are reasonably representative of the whole population.

We also note that the Google Analytics result only includes requests from the web site but not from mobile platforms.

5.6.7. Voluntary User Survey

There were two voluntary surveys that the users could take to give feedback, one was the web based survey (see Appendix B) and the other was a simple survey on the mobile phone.

A. Web Survey Responses

A survey posted on the Path2Go website obtained user feedback for the web application. Fifty-one responses have been collected throughout the study period.

First, users were asked to rate the Path2Go applications on a scale of good-neutral-bad. Results are shown in Figure 5-36.

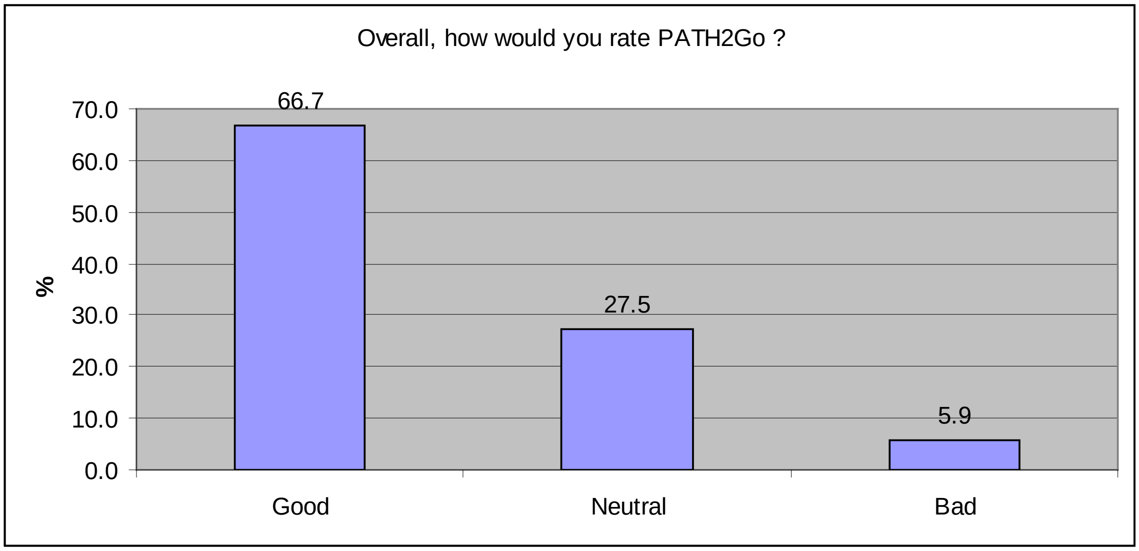


Figure 5-36 Overall rate of Path2go by respondents

While approximately two-thirds of the users gave “good” ratings, a significant minority of users gave no clear response, and about 5% of the users were not satisfied with the applications.

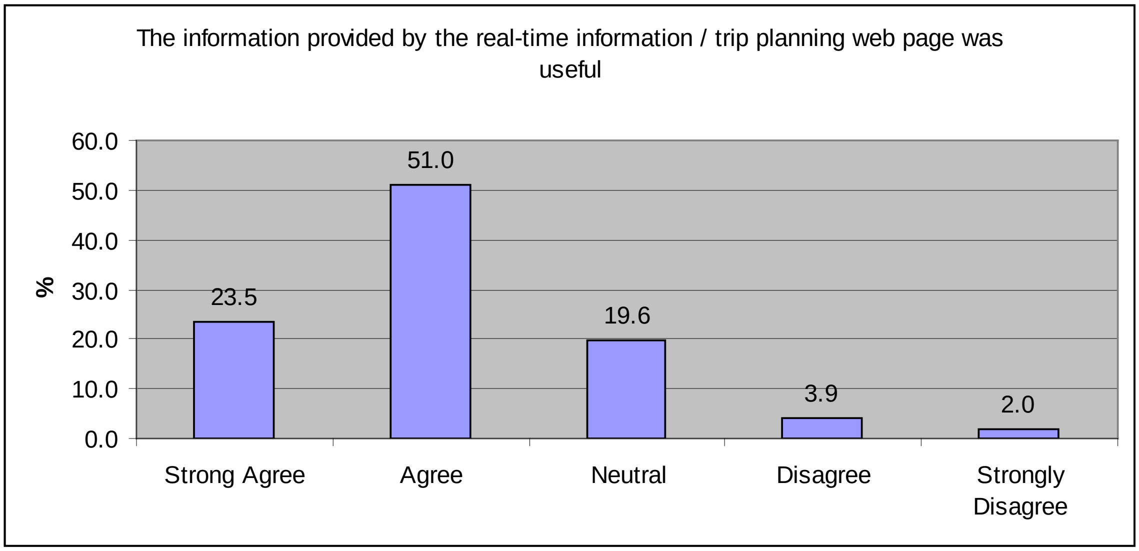


Figure 5-37 Survey result of usefulness of real-time information of Path2go

Figure 5-37 above summarizes respondents' views on how useful the information presented in the webpage was. As shown, over 70% of the users find the website useful. Conversely, about 6% of the users disagreed that the information was useful. It would appear that most users did find the website helpful.

Additionally, there was relatively strong agreement that real-time information provided on the website was valid (Figure 5-38), while 6% of the users disagreed, 66% reported that they "strongly agreed" or "agreed" that the information was reliable.

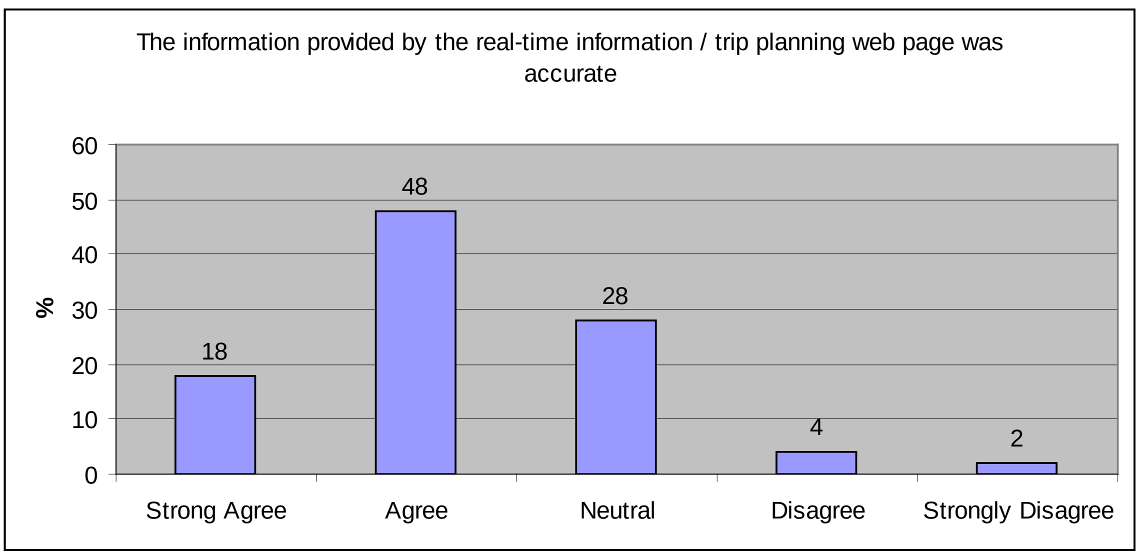


Figure 5-38 Survey results of accuracy of Path2go real-time information

The users also reported generally positive opinions on whether the application helped them reduce their waiting time:

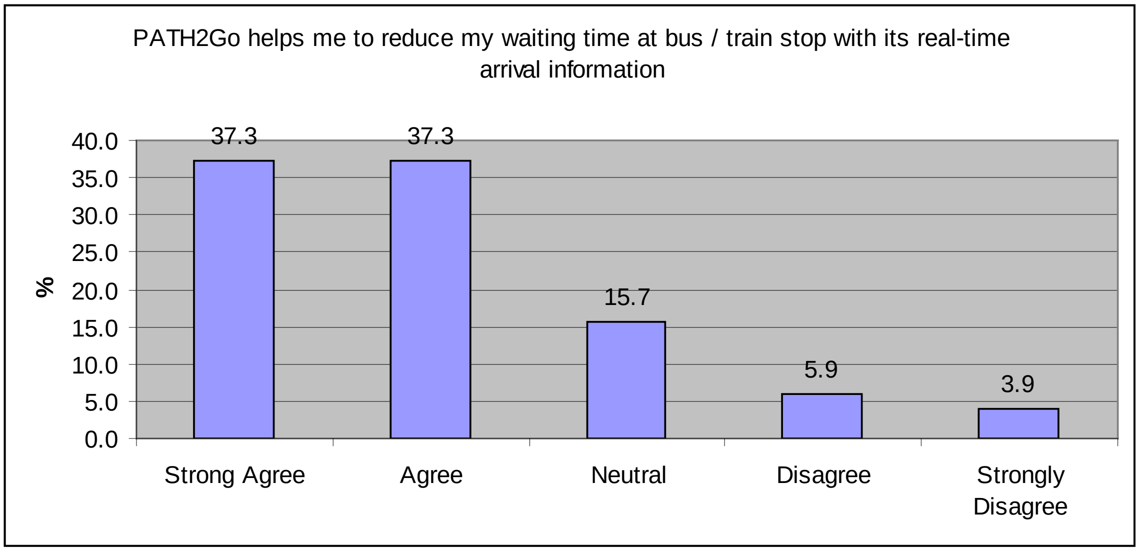


Figure 5-39 Survey results of reducing waiting time by using Path2go

As shown in Figure 5-39 above, 75% of the users feel that the Path2go arrival information helps them reduce their waiting time at transit stations. On the other hand, less than 10% of the users held opposite viewpoints.

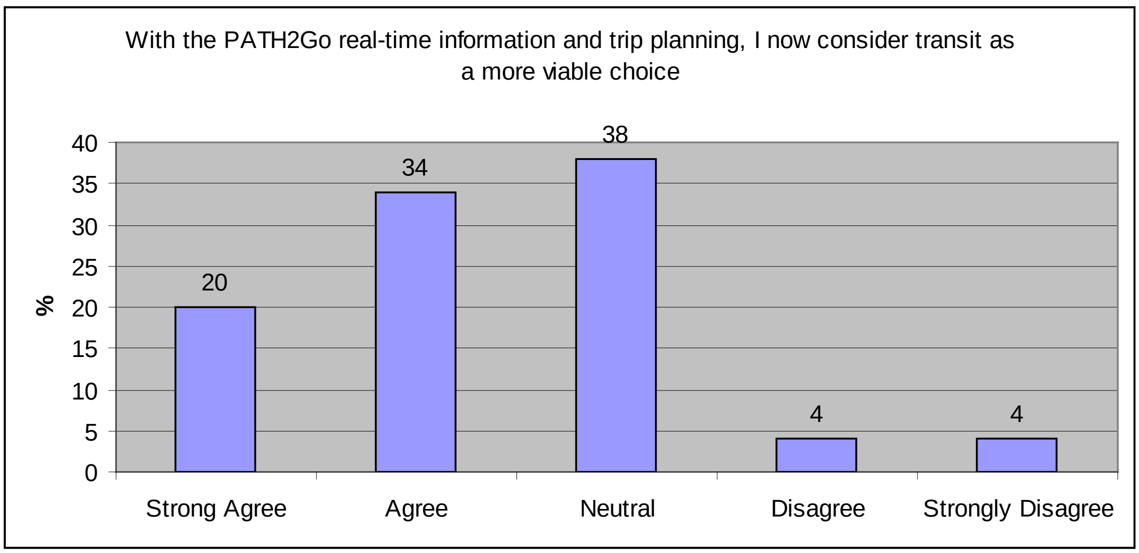


Figure 5-40 Survey results of considering transit as more viable choice after using Path2go

Figure 5-40 above shows that about 54% of the users feel that using the applications would cause them to consider commuting with transit and about half of the users still feel unsure or decided not to switch. Since it is estimated that about half of the users were traveling with transit in the first place, it is difficult to tell whether drivers decided to switch to transit based on information obtained in this survey. However, one may propose that with the Path2go application, it is more likely for drivers to switch to transit than for transit users to switch to driving.

B. Cell Phone Survey Responses

A simple survey was requested from the Path2Go cell phone application users. The survey only had one question: Is the application useful? (2 for useful, 1 for neutral, 0 for not useful) 31 responses were gathered, with the following results:

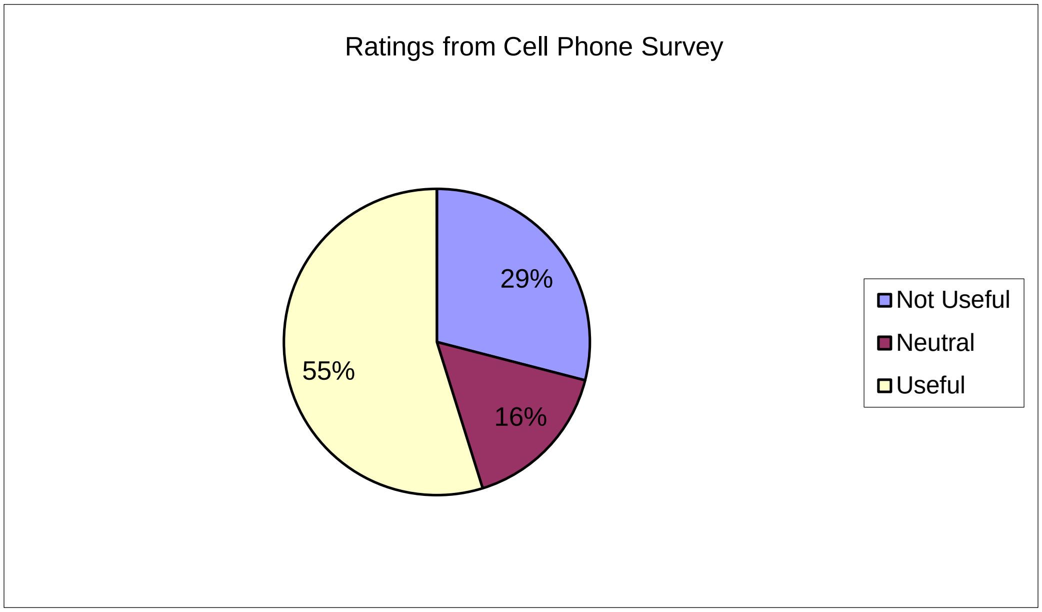


Figure 5-41 Survey results of usefulness of mobile Path2go application

The results in Figure 5-41 showed that more than half of the users found the application useful. However, the high amount of users who weren't satisfied with the application indicates that there is still ample room for improvement.

C. Comments and suggestions brought up by respondents

From the comments section, users generally brought up the following concerns/improvements:

1. Include incident news feeds that show transit delays
2. Load/Save function for favorite trips
3. Need static system maps of transit agencies to gauge where origin/destination stations are located
4. Inaccurate information—sometimes trains/buses arrive early
5. Incorporate information for AC Transit
6. Provide multiple transit options
7. Only a few stations show parking spots
8. Application to zoom-in on the user instead of showing the map at a city level
9. More user-friendly screens
10. The need to log on discourages many users, the number of clicks to access the desired information should also be reduced

These suggestions are helpful and will be input for the improvement of Path2go in a follow-on project.

5.6.8. Conclusions of user data analysis

Users of the Path2go applications were asked to provide feedback to the applications. Two hundred forty-four surveys regarding the demographic characteristics and usages were received. In addition, 51 completed web surveys and 31 cell phone surveys were also collected.

The majority of the survey respondents belong to the upper middle class, with half of the respondents having annual incomes of over $100,000. The survey results indicate that, the commute trip distance is diversified, with the median trip distance of slightly less than 20 miles. Most of the trips undertaken by the respondents are less than 45 minutes. More than 40% of the respondents reported using 2 or more modes for commuting. In addition, 60% of the survey respondents considered transit as a mode of choice, followed closely by driving at about 55%. Carpooling and other mode choices remain unfavorable to the majority of respondents. When asked about the number of traffic information sources utilized, about one quarter of the respondents indicated that they do not seek such information, while 43% use only one information source. 511 services are considered the most popular type of information source, used by over 40% of the respondents, followed by Google with a 30% usage rate.

For the web surveys, two-thirds of the respondents considered the Path2go applications satisfactory, while 27.5% have no opinion and 6% gave the applications poor ratings. In general, well above half of the respondents indicated that the information provided was useful, accurate and helpful for them to reduce waiting time. They stated that the information had influenced them to consider transit as a more viable choice. Users also provided comments for possible technical and service improvements such as to load/save favorite maps and to incorporate information for AC Transit, a major Bay Area transit service provider.

The cell phone survey received positive overall ratings, with more than half of the users finding the application useful. However, the high dissatisfaction rate shows that there is still space for improvements, particularly the user interface.

As can be seen from the data, the Path2go application attracted a steadily increasing number of users during the FOT testing period, a majority of which are from the US-101 corridor, i.e. our FOT testing site.

The usage data analysis also showed a normal usage pattern for the users. Users have been using the applications to do trip planning and finding real-time transit information, using both web and mobile platforms.

5.6.9. Summary of Eevaluation Results from the Independent Evaluator's Report

The independent evaluator has conducted a web survey with one hundred and twenty valid responses. The major results from the survey questions that are directly related to the research objectives are listed in Table 5-14 below.

Table 5-14 Survey results from the independent evaluation report

Question	agree/strongly agree	disagree /strongly disagree
Application provided valuable information	**56%**	**14%**
Ability of access information for multiple agencies is useful	**65%**	**10%**
Information is accurate	**40%**	**12%**
Information of path2go makes me feel more confident about using public transit	**40%**	**20%**

32% respondents indicate that Path2go makes them more likely to choose an alternative mode (while 38% not).

More analysis and evaluation of the FOT data can be found in the independent evaluator's report (38).

5.7. Smart Parking Testing Results By ParkingCarma

ParkingCarma's role changed during the project initially due to contract delays and subsequently due to Caltrans deciding that they did not want to deploy additional sensor systems along their parking facilities.

ParkingCarma learned the following from the research conducted:

1. ParkingCarma implemented a camera based detection system at Redwood City in late 2009, and collected data from the location continuously from then on except for a one

month period when the system was removed and sent back to Aldis for repairs. The parking facility had 315 parking spots.

- The camera detection system was installed on the outside of an entrance to a garage and recorded the entrance and exit of vehicles, fed the raw data to the ParkingCarma web site where the inventory was incremented or decremented in near real time.
- Observations on performance:
- The feeds from the camera to the PC site depended on GPRS, and the cellular network was not consistently reliable. The camera system had a store and forward capability so the data would be streamed to PC site, but not always at the time of the events. A direct Internet connection would be preferable for performance.
- The detection of ins and outs was reliable to the extent that the count of ins was usually about 5% less than the count of outs. The discrepancy was most evident during high entrance times during the morning. It appears that if cars are virtually in a line entering the facility, the camera would not record the pixel movement as a separate automobile. On the exit side, the reporting was consistently accurate – apparently the result of cars leaving at a better distance between them. We normalized the counts by factoring in the discrepancy to provide a reliable indicator of availability.

The discrepancy in entry and exit shown on the graph is representative of the system. There were a total of 180 cars entering and 192 leaving

Entering			**Exiting**	
1/25/2010	4:51:55		1/25/2010	6:09:29
1/25/2010	4:58:51		1/25/2010	7:12:14
1/25/2010	5:11:04		1/25/2010	7:43:43
1/25/2010	5:34:43		1/25/2010	7:54:39
1/25/2010	5:58:12		1/25/2010	8:44:05
1/25/2010	6:06:21		1/25/2010	9:27:33
1/25/2010	20:24:02		1/25/2010	20:05:23
1/25/2010	20:57:59		1/25/2010	20:19:10
1/25/2010	21:42:54		1/25/2010	20:19:45
			1/25/2010	20:20:50
			1/25/2010	20:22:22
			1/25/2010	20:22:25
			1/25/2010	20:28:32
			1/25/2010	20:28:39
			1/25/2010	20:33:28
			1/25/2010	20:34:09
			1/25/2010	20:38:30
			1/25/2010	20:38:37
			1/25/2010	21:42:42
			1/25/2010	21:45:45
			1/25/2010	22:41:53

- The camera system is technically acceptable for counting but not cost effective for the value delivered at least at the Redwood City garage. The camera along with GPRS communications installed is around $20,000 for a similar configuration at Redwood City.

2. Giants Stadium Parking Lot
   - We installed a loop sensor system at Lot C located two blocks from Caltrain station. The surface lot had two entrances/exits and is primarily used during special events and baseball games and has 800 parking spaces.
   - General Observations

i. The loop sensors performed accurately except under extreme stress of traffic when the lot operator would have to move the cones and direct the traffic away from the loop sensors in order to prevent parking traffic from blocking traffic on 3rd Street in San Francisco.

ii. A camera was also installed on the sensor box for forensic purposes. It did not do any sensing. By comparing camera images with the sensor feeds, a margin of error of around 2% was typical. Unlike the camera system in Redwood City, the margin of error was not consistently on ins or outs. It made it difficult to normalize the feeds.

Date/Time	In Lot	Out Lot	Total In	Total Out	Lot Occupancy
10/8/10 12:15 AM	0	1	0	1	-1
10/8/10 12:30 AM	3	1	3	2	1
10/8/10 12:45 AM	1	1	4	3	1
10/8/10 3:00 PM	10	0	55	24	31
10/8/10 3:15 PM	12	1	67	25	42
10/8/10 3:30 PM	11	0	78	25	53
10/8/10 3:45 PM	10	1	88	26	62
10/8/10 4:00 PM	20	1	108	27	81
10/8/10 4:15 PM	22	2	130	29	101
10/8/10 4:30 PM	24	0	154	29	125
10/8/10 4:45 PM	16	13	170	42	128
10/8/10 10:30 PM	0	16	426	123	303
10/8/10 10:45 PM	0	84	426	207	219
10/8/10 11:00 PM	0	121	426	328	98
10/8/10 11:15 PM	1	66	427	394	33
10/8/10 11:30 PM	0	17	427	411	16
10/8/10 11:45 PM	0	2	427	413	14
10/9/10 12:00 AM	0	7	427	420	7

iii. The parking management company, Impark, gave the system a B+ grade and intends to expand its usage to Lot A at their expense. It served its purpose for them. The city of SF has an ordinance that requires surface lots report actual usage for reconciliation. The purpose is to prevent the loss of money since it is a cash business.

iv. PC also offered pre-paid reservations in the facility. The use of pre-paid reservations was high during the Paul McCartney concert (77 pre-paid reservations), but not widely adopted during the baseball games (10-20 during week end games). Impark and PC are analyzing methods to improve that next year.

v. A use for the parking facility that we are exploring is to mitigate congestion in SF by routing parking traffic during non-baseball days to the lot, allow the purchase of a MUNI day pass, and then use the MUNI station at the lot to travel to the highly visited parts of the city, such as Fisherman's Wharf, China Town, etc. The parking cost would be $5-$8 versus the $20-$25 elsewhere, and pull significant traffic off the streets.

vi. The loop sensors used GPRS for communication and solar for power. The GPRS in that area was consistently reliable to maintain continuous feeds. It took Case Systems roughly two months to calibrate the sensor feeds to provide reliable data feeds. The cost of $16,000 requires that the system be able to do more than count availability on an irregularly used facility. On the other hand, it probably paid for itself as the policeman in the eyes of the money collectors – the amount of slippage decreased significantly according to Impark.

3. Count Normalization
    - PC customized its counting system to adjust to time of day discrepancies and to predict future availability based on statistical normalization. The predictions are based on 15-minute windows enabling a traveler to view a facility and get an estimate of what availability would be like when he is most likely to arrive. The problem addressed is providing information that is accurate at the moment requested, but not usable for several minutes later due to drive times to the facility. Since the driver could be on the highway at the time of interest, the parking facility could be 15 to 20 minutes away. Additionally, in the case of Caltrain, selecting the correct lot (East Side or West Side) with proper guidance is crucial. If the driver selects the East Side, and the lot is full, it can take an additional 10 minutes to navigate to the other side of the tracks.
    - Subsequently, PC customized the availability display to show availability in a red-yellow-green format to account for both the inherent inaccuracy of the data and the latency between the time of request and time of need. This work was not within the scope of the Safetrip 21 project, was done in concert with our truck project, and not billed to ST 21. However, it is available to ST 21. The color zones were divided into the following categories: more than 75% available – Green; between 5% and 25% available – Yellow; and less than 5% - Red.

5.8. Lessons Learned and Future Improvements

5.8.1. Major Lessons Learned

A. Management of the risk of integration of data from multiple agencies for system interoperability

One of the major lessons learned during the Networked Traveler field test was the complexity for the Path2go system to be integrated with all systems that provide static and real-time data. . As an integrated multi-modal traveler information system, Path2go has a major advantage over other systems as being more integrated with multiple agencies and multiple travel modes. However the integration raises two levels of complexity for the project: one is the technical level and the other is the institutional level.

On the technical side, the current state of various systems from transit operators and traffic data sources are mostly non-standard (or even there is no appropriate standard at all) and different. For the static transit information included in Path2go system, we have had the following types of data formats:

- GTFS (Google transit file specification) for VTA, BART, Caltrain and SF Muni;
- XML based format for SamTrans; and

While for the real-time data feed, there are three different systems:

- Public real-time GPS location provided by Nextbus; (SF Muni) ;
- GPS location update from ACS internal interface (SamTrans); and
- BART real-time predictive arrival time public API (BART).

In addition to these data feeds, PATH has developed its own AVL system as a cost-effective means to collect real-time data for Caltrain and VTA BRT 522 line when the real-time data is not available from the operators.

Data elements required to generate high quality predictive arrival time information are sometimes missing. For example SamTrans does not have up-to-date route shape information for bus arrival time prediction purposes. That part of the data has to be manually extracted from the route map and input into the database.

The integration of these different data sources into Path2go and the development of extra software code to make them interoperable have been a tremendous undertaking, and greatly exceeded the previous estimation of resource expenditures.

Regarding the institutional issues, Path2go includes data from a number of Bay Area transportation agencies including, Caltrans, Samtrans, VTA/Caltrain, BART and Muni. Arrangements for obtaining the data require installation agreements in most cases. Furthermore, the quality, format and interfaces for both static and real-time are very different. In some cases, although the operating agencies own the data, the database that holds the data and supports the operation of the systems are usually proprietarily designed and will require modification by the vendor in order to enable the data to be shared with Path2go. The mix of the institutional arrangements and technical solutions has demanded significantly more effort than initially planned in order to resolve the complicated 'data issues'.

Substantial lessons have been learned from making institutional arrangements for obtaining data. As the complexity of these arrangements were typically unknown at the proposal state, it is imperative to make plans at the early stage of the project to identify both technical and institutional uncertainties from system integration with multiple systems across multiple agencies, to include adequate efforts for making institutional arrangements and to devote consistent efforts to resolve these issues.

B. Understanding the complexity of geofencing and the compromise of usability

The re-scoping of the project has put a prerequisite condition on the project before its public launch to ensure that the application won't be found useful for drivers. Accordingly, a geofencing concept was proposed, involving functions to disable the display while the user is detected to be more likely driving based on the GPS data. In the previous section, we have discussed that this function is currently not available from commercial-off-the-shelf products.

Users of geofencing challenged the necessity in the design when the application was intended to be used for transit riders. The perspective from the users regarding the geofencing design is another major lesson we learned from the field test. From users' perspective it is more less desirable to have a geofencing design that 'disables' the display comparing to other less intrusive designs such as pre-trip warnings.

Another challenging task is the detection of the activity of the user from mobile phone data. The detection can have errors and therefore false warnings could be given to users. This is especially difficult before the user has submitted a trip, in which case not much information can be used other than GPS speed before the GPS data can be matched to a running bus or train. The match usually requires at least three samples of GPS traces, which could take a while, especially considering the fact that the GPS update rate for most routes are around two minutes and multiple GPS samples are needed to do a match. False warnings compromise the usability of the application, even though the chance of false-fencing is low, Therefore the threshold or parameter setting of the detection during the pre-trip stage is more of a trade-off of geofencing or usability consideration. The design of the FOT was for geofencing to ensure fewer missed detections. Based on the feedback from the survey we learned that those false alarms have been very annoying to the users and the compromised usability was apparently a much bigger concern by the users than the safety benefit.

C. Understanding user needs

Partly due to the tight schedule of the application development and the delay caused by institutional issues, we were not able to go through a formal process to analyze user needs and to develop a formal requirements analysis from the user's perspective. Our major focus was on the development of a database for different transit agencies, incorporating data, solving the interoperability issues and developing geofencing after the re-scoping to make the FOT happen. Not enough time remained when all these earlier tasks were completed before the roll out of the system.

The users, who were recruited from the general public, do have a different perspective of the Path2go application than researchers working in the field. This is especially true with regard to the usability and user interface (UI) design. Therefore the UI design, in terms of ease of use, user friendliness, etc, still has room to improve. The evaluation report from the independent evaluators also showed that the overall survey feedback on the user interface of the application gained a lower score than those of functions and accuracy of information from the application.

5.8.2. Future improvements

Caltrans and PATH will continue the development of Path2go under the 'Smart Traveler' project. PATH has proposed the following aspects based on the experience of the NT FOT to further improve Path2go:

1. Increase coverage of real-time transit information for the San Francisco Bay Area
Currently Path2go covers real-time information for BART, SF Muni, SamTrans, Caltrain and VTA BRT 522.

- During the new project, all AC transit (ACT) routes will be added to Path2go, including their static schedule data and real-time information; Route shape information for ACT routes will need to be developed (manually input and map-matched to GIS database) and later on maintained by PATH.
- Work with VTA to integrate their real-time data sources into Path2go.
- We desire to include real-time data from more transit agencies if possible.
- We will also work with SF to seek possibilities of including SF real-time parking data.

2. Improve performance and usability of Path2go:

1) Change of Path2go multimodal application to (a) significantly improve response speed of trip planning from its current value of 3-4 seconds; (b) improve the transit AVL data sampling rate, which is usually low. It is essential to extend Path2go to include a GPS-fusion feature so that high quality GPS data from user smart phones can be fused with AVL data (when available) to generate bus prediction and timely alerts for all users, to improve availability and accuracy of bus real-time prediction results; (c) give detailed directions for walking during the transfer process. The current system assumes that passengers know the walking direction(s) well, which may not be true for some passengers.

These changes would require a major redesign and implementation of the Path2go application.

2) Improve the user interface design for better usability

Both the web interface and mobile interface (for Android as well as iPhone) will be redesigned to make the user interface easier to use, more intuitive and present the information in a more organized way.

3) Incorporate new features based on user feedback from the Networked Traveler field operational test.

3. Evaluate and improve the presentation of multi-modal traveler information for greener trips

Improving the presentation of the emissions savings for transit and modes other than driving is important for the purpose of encouraging mode shift of travelers. With the Smart Traveler project, we plan to explore and evaluate the information presentation methods with the Path2go application to improve the effectiveness of these methods.

4. Evaluate the implementation strategy for geofencing based on the survey data from the Networked Traveler FOT and revise the design accordingly to minimize its negative impact on the usability of the application while still conforming to state law.

5. Integrate a multi-modal aspect on the mobile Path2go system.

The Path2go mobile application will be improved from its currently transit-only application to a multi-modal application, which will support driving-to-transit mode, biking etc. This task will be implemented jointly with task 4 (Geofencing) to ensure safety when using the application.

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Appendices

Appendix A. Path2go Application and Related Web Resources

Table. A-1 Path2go applications and web resources

Path2go Application	URL	Note
Networked Traveler	www.networkedtraveler.org	The project website
Path2go web trip planner	http://tlab.path.berkeley.edu:8080/dpiVII?p=true	URL to the web based Path2go multimodal trip planner. It is linked to from the project website
Path2go real-time transit information viewer	http://tlab.path.berkeley.edu:8080/dpiVII	URL to the real-time transit information web page of Path2go, for searching and viewing real-time transit arrival and Caltrain parking information (selected lots only)
Path2go mobile app	www.networkedtraveler.org/mobile.php	The information page on how to download the mobile application for Path2go
GPS Tracker status viewer	http://tlab.path.berkeley.edu:6060/viewer/viewer.php	Real-time status of the GPS tracker status, for internal usage and operators

Real-time arrival at Millbrae transit center	http://tlab.path.berkeley.edu:8080/SamTransKioskMillbrae/index.html	The online link to the real-time kiosk display at Millbrae station (must use a screen with resolution greater than 1600 * 1200 for distortionless display)
Real-time parking lot information page	http://tlab.path.berkeley.edu:8080/dpiVII/sm/parkinglots.jsp	For internal usage only, show the real-time parking availability as well as the vehicle movements at the parking lot entrances and exits.

Appendix B. Path2go Surveys

A. Post-account-creation survey

Please help with our research by telling us a little about yourself:

1. What is your home zip code?

2. About how much is your yearly household income?

3. What industry do you work in?

4. For which of the following purposes did you sign up the Networked Traveler application?

- ☐ Commute to work or school
- ☐ Personal travel (e.g., shopping, medical appointments, recreation/vacation)
- ☐ Business-related travel (e.g., deliveries, business appointments)
- ☐ Other (specify)

5. Most days, about how long is your commute in miles (one way)?

6. Most days, about how long is your daily commute in minutes (one way)?

7. Most days, how to you typically commute (check all that apply)?

- ☐ Car
- ☐ Local Public Transit (Within a City, e.g., Muni)
- ☐ Regional Public Transit (Between Cities, e.g., Caltrain, BART)
- ☐ Private Transit (e.g., Company Shuttles)
- ☐ Carpool
- ☐ Other (specify)

8. Where do you normally get your traveler information (check all that apply)?

- I don't usually check traveler information
- Google Website
- 511.org Website
- 511 (phone)
- Radio
- Electronic message signs along my route
- Television
- Other Website:
- Other Mobile Phone Application:
- Other (specify)

9. How did you hear about us?

- 511.org Website
- iTunes Store
- Android Market place
- Google
- A friend or relative told me about it
- Other (specify)

B. *Voluntary web survey*

Please help with our research by filling up the following survey. Your responses are very important to us and we are looking forward to hearing from you.

Overall, how would you rate Path2go ?	Bad	Neutral	Good
	●	●	●

		1	2	3	4	5	
The information provided by the real-time information / trip planning **web page** was useful.	Strongly Disagree	●	●	●	●	●	Strongly Agree
The information provided by the real-time information / trip planning **web page** was accurate.	Strongly Disagree	●	●	●	●	●	Strongly Agree

Path2go helps me to reduce my waiting time at bus / train stop with its real-time arrival information.	Strongly Disagree	1 ●	2 ●	3 ●	4 ●	5 ●	Strongly Agree
With the Path2go real-time information and trip planning, I now consider transit as a more viable choice.	Strongly Disagree	1 ●	2 ●	3 ●	4 ●	5 ●	Strongly Agree

Do you have any additional comments about Path2go?

Appendix C. Layouts of Instrumented Parking Lots

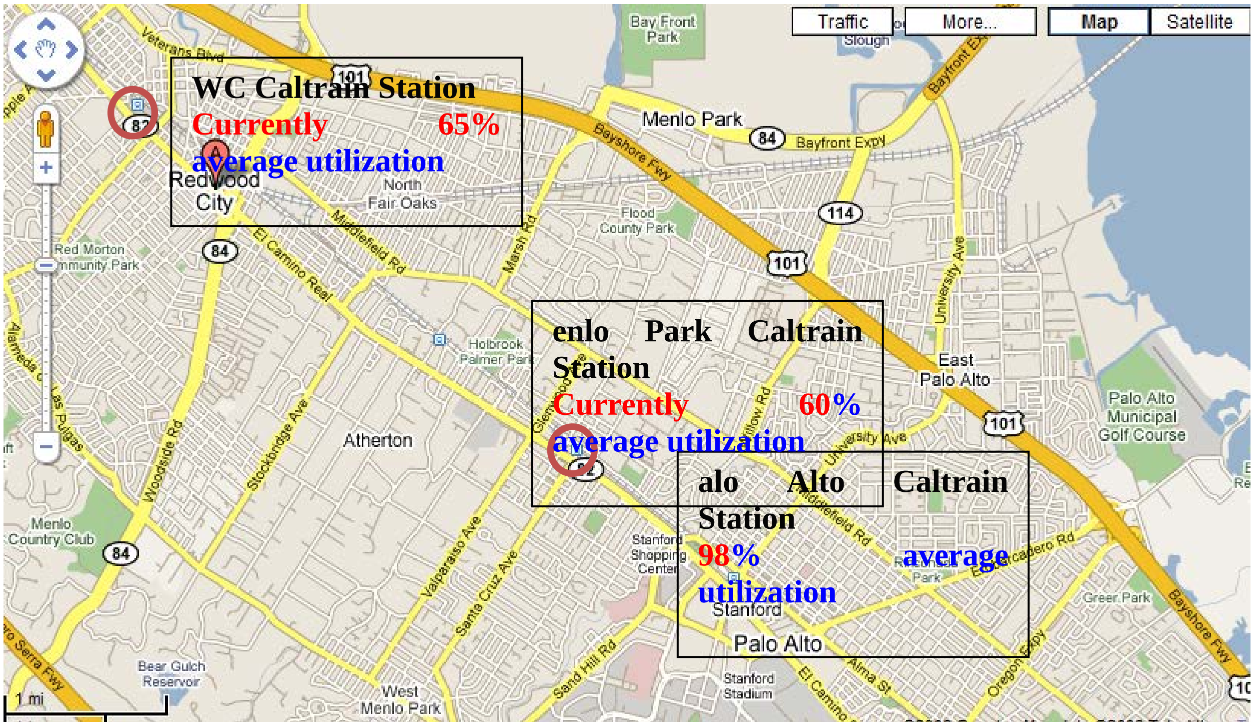


Figure. C-1 Selected Caltrain Stations

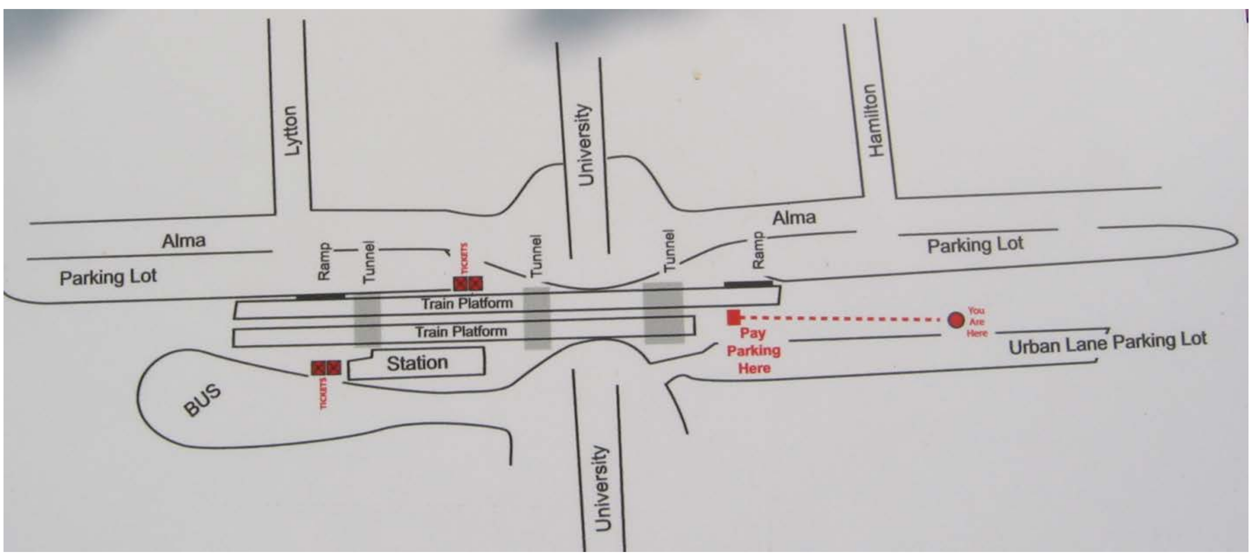


Figure. C-2 Layout of Parking Lots at Caltrain Palo Alto Station

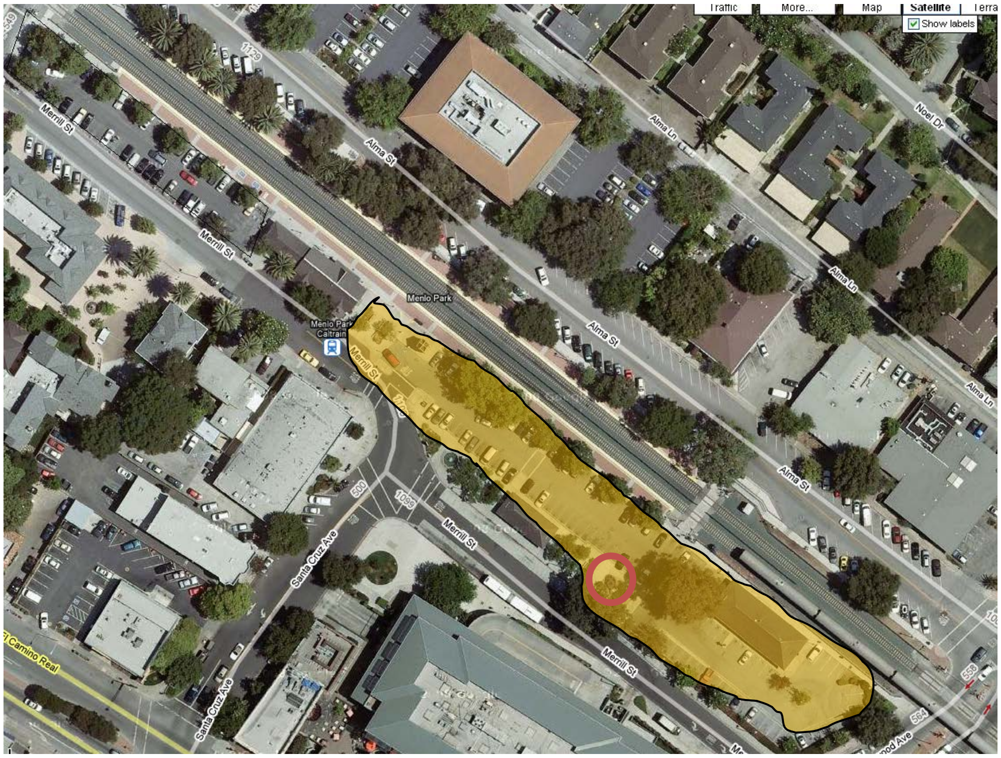


Figure. C-3 Caltrain Menlo Park Station Parking Lots Layout (shaded Area)

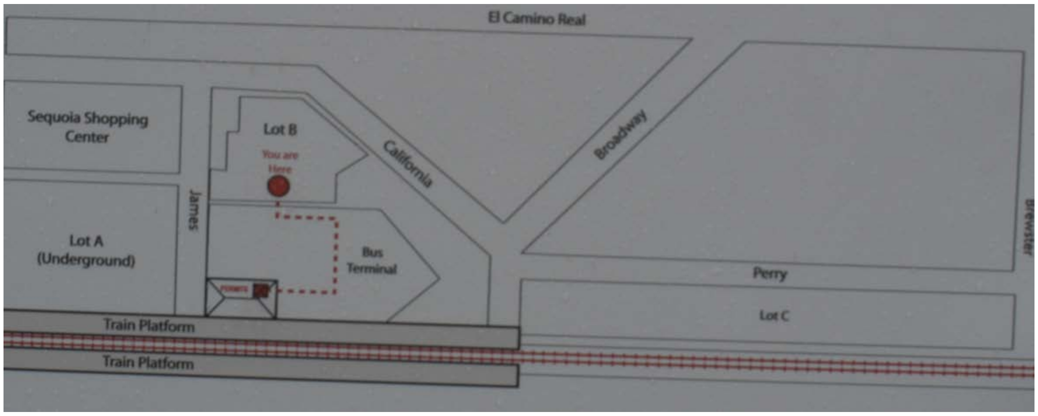


Figure. C-4 Caltrain Redwood City Parking Lot Layout

Figure. C-5 Millbrae Parking Lot Layout

Appendix D. Implementation Details of Multimodal Trip Planner

A. *Construct the underlying network*

Due to the nature of multi-modal transportation, our underlying network consists of different types of nodes, including intersections, bus stops, train stations, parking lots, and transit time points. First, we construct two types of networks: road network and transit networks. The road network consists of intersections, transit stops and parking lots. The time points are excluded in the road network. The road network includes arcs between intersections, arcs between intersections and transit stops, and arcs between intersections and parking lots. The road geometry data in our system is from NavTeq. The stop and parking lot data is from various transit agencies.

The walking mode presents two issues that need to be addressed: (1) walking on freeways is disallowed; and (2) for one-way roads, walking may be allowed in both directions. Each arc in the underlying network is associated with certain indicators to show if the road is a freeway, local street, two-way or a one-way road. The planning algorithm will examine the road type and transportation mode together to see if it is reasonable to use the road.

The transit networks include transit stops, parking lots, and time points. The arc types are: a stop to related time points, a pairing lot to related time points, time points to time points of the same route, the time points to time points of different routes, time points to stops and time points to parking lots. Transfer between different routes is very important in underlying network construction. First, we examine the possible transfers based on the static schedule data and minimum transfer time. Then, the planning server periodically queries the estimated transit arrival time from the database. If a transit vehicle arrives at a stop late and the original transfer is infeasible, the corresponding arc is disabled in underlying networks.

Note that designing transfers between different routes is crucial to obtain reasonable trip plans. Bus routes serve many bus stops (i.e., 100 stops for some routes in San Francisco). Only a small percentage of bus stops have time points. These stops are called *time-pointed stops* in this report. Bus drivers use these time-pointed stops to maintain the schedule. The bus stops that do not have associated time points are called *non-time pointed stops*. Some trip planners allow passengers to transfer to a different route only if two related stops have time points. Such an approach significantly reduces the size of the underlying network and decreases the response time of the planning server. However, our preliminary studies show that certain trips are inappropriate. For example, a passenger may have to travel back-and-forth between stops. If transfers are allowed in both time-pointed stops and non-time pointed stops, the network size is very large, thus significantly increasing computational time. In order to handle the trade-off between improving trip reasonableness and reducing the computational time, we use different distance thresholds for transferring at different types of stops: for two time-pointed stops, the maximum allowable transfer distance is 800 meters; otherwise, the maximum distance is 100 meters. Certain simple averaging methods are used to estimate the static arrival time to non-time pointed bus based on the route schedule and distance between bus stops.

The transit network includes cycles. For example, a circular route may exist. However, if the underlying network is acyclic, more efficient algorithms are available. In order to get an acyclic network, each bus stop in the transit network is split into two bus stops: a starting bus stop and an ending bus stop. Two corresponding arcs are (1) from the starting bus stop to a time point; and (2) from the time point to the ending bus stop. Such a stop splitting strategy leads to an acyclic transit network.

Since most transit agencies have different services on weekday and weekends, we construct three transit networks: weekday transit network, Saturday transit network, and Sunday transit network, each of which contains the time points for that day. It is worthy to note that all the networks are shared by the trip planning threads (see Figure 4-2) for saving computer memory. Due to a large number of intersections and time points, the road network and transit networks are very large. It is critical for planning threads to share the data.

When real-time passenger information is available, the real-time transit arrival and travel time is updated periodically in the database. A thread is implemented to query the real-time data from the database and to update corresponding networks. Certain arcs may be disabled if transit vehicles arrive late. Some locking mechanisms are used in the programs for mutual exclusion between different threads.

B. Trip planning algorithms

When users choose to drive from a given origin to a destination, the quickest route is returned. If users choose the mode of transit only or park-and-ride, we first select the transit stops or parking lots that are near the origin. Then, the transit stops nearby the destination are determined. In summary, we solve three kinds of shortest path problems: (1) from the origin to the nearby transit stops or parking lots; (2) from the destination to the nearby transit stops; and (3) from the transit stops or parking lots that are close to the origin to the transit stops that are close to the destination. These routes will be combined together to yield an overall route.

Label setting algorithm for driving and walking modes

There are three situations where the one-to-one shortest path problem needs to be solved: (1) driving-only mode with an origin and a destination; (2) driving or walking from the origin to the first bus stop; and (3) walking from the last bus stop to the destination.

We implement a Dijkstra algorithm to solve the one-to-one shortest path problem. The Dijkstra algorithm is a label setting algorithm, and the complexity is $O(n^2)$, where n is the number of nodes in the network. The bi-directional Dijkstra algorithm may be used to reduce the computational time since the bi-directional Dijkstra algorithm is expected to have a better performance for the node-to-node shortest path problem (Ahuja, Magnanti, & Orlin, 1993). Our experiments show that the one-to-one shortest path problem can be solved very quickly.

Multi-source time-dependent shortest path algorithm for the transit mode

When the transit-only mode or park-and-ride mode is selected, the users provide the expected departure time or arrival time. Some arcs may not be valid with the specified time. For example, if a user expects to depart at 7:00AM, the arc from the transit stop to a trip starting at 6:40AM is invalid. Therefore, finding paths between two transit stops is a *time-dependent* shortest path problem. The time-dependent shortest path problem has been investigated by forward/backward searches (Chabini, 1998) (Huang & Peng, 2002) (Tong & Richardson, 1984) and dynamic programming (Zografos & Androutsopoulos, 2008). Since the transit network is acyclic, the topological sorting algorithm (Chakroborty & Kikuchi, 2004) can be used to find shortest paths with the complexity of $O(m)$, where *m* is the number of arcs. Note that *m* is far less than n^2in sparse networks, thus decreasing the computational time.

As mentioned before, when users specify an origin and a destination, nearby bus stops are determined. Our experiments show that good trips may be omitted if insufficiently nearby stops are used. Currently, for each origin and destination, we select 50 nearby bus stops. However, the computational time is significant if 50 one-to-many shortest path problems are solved, even with the acyclic transit network!

We design a multi-source shortest path algorithm for reducing the computational time. Note that in the typical one-to-many shortest path algorithm, only the source node is pushed into the candidate list during the algorithm initialization. We first calculate the travel distance from the origin to the nearby bus stops. The arrival time to each nearby bus stop can be determined accordingly. Then, these nearby bus stops are pushed into the candidate list with the arrival time. The travel distance from the origin is used as the initial cost for each nearby stop. Our multi-source shortest path algorithm requires solving only one shortest path problem, thereby substantially reducing the computational time.

In the one-to-one label setting problem, the algorithm can terminate when the destination is reached (Chakroborty & Kikuchi, 2004). However, it is difficult to determine such early termination rules in our multi-source shortest path algorithm since the algorithm is not a label setting type. In order to further reduce the computational time, we use a box to limit the nodes that the algorithm is visiting. Note that every node in the transit network has latitude and longitude. With the origin and destination given, we can construct a box where the origin and destination are two diagonal nodes (see Figure. D-1). However, it is possible that some good trips are outside this box. Therefore, we enlarge this box so that four lines of the box are moved outward to some extent. In the current implementation, we moved each line outward 5 miles. The following procedure is used to approximate the latitudes and longitudes of four nodes of the enlarged box: 1^o of latitude $= 69$ miles, and 1^o of longitude $= 69 \times \cos(\text{latitude})$ miles.

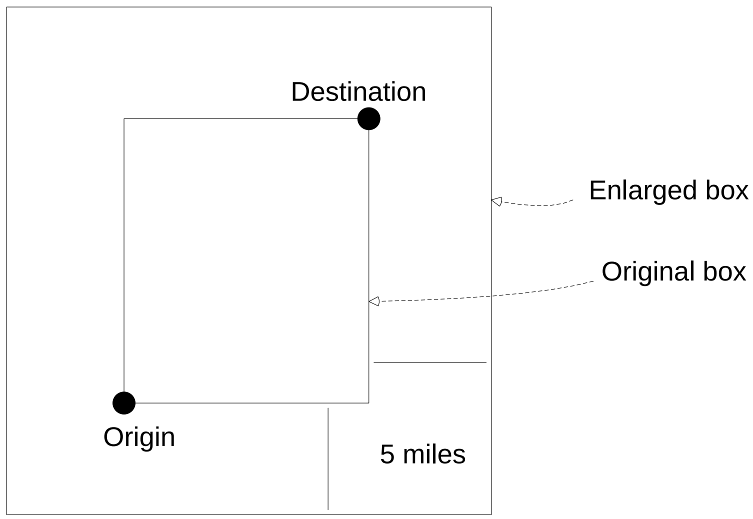


Figure. D-1 An example of the use of enlarged box to limit node visiting

It is worth mentioning that our multi-source time-dependent algorithm consists of a forward algorithm and a backward algorithm: the forward algorithm is used when the users specify the departure time, while the backward algorithm is used when the expected arrival time is specified. Two algorithms have similar operations except with initial sources and the arc scanning method.

C. Trip dominance

After the multi-source time-dependent shortest path algorithm is finished, we can retrieve a shortest path for each nearby ending bus stop. In most cases, some shortest paths may be very similar. For example, when there are two stops on the same route; and both of the two stops are close to the destination. Therefore, two associated trips are almost the same except for the last bus stop and walking route to the destination.

It is necessary to examine the similarity between trips. We design certain dominance rules to discard trips. First, for all the trips, we determine the following criteria: minimal number of transfers, earliest arrival time, latest departure time, minimal travel distance from the origin to the first stop, minimal travel distance from the last stop to the destination. If a criterion of some trips is considerably worse than the best one, it is discarded. Such dominance rules effectively reduce the number of similar trips.

D. Overall procedure

The overall trip planning algorithm is as follows:

Step 1: Based on the origin and destination, determine the nearby bus stops using Euclidian distances.
Step 2: Apply Dijkstra algorithm to obtain the shortest path from the origin to its nearby bus stops and from the destination to its nearby bus stops.
Step 3: Push all the nearby bus stops into the candidate list during the initialization stage and solve the multi-source time-dependent algorithm.
Step 4: Merge transit trips and associated walking trips and/or driving trips together to have complete trips.
Step 5: Apply dominance rules to discard similar trips.

E. Case studies

Our trip planning server is implemented in C++ on a Lenovo Thinkstation with 4 Intel processor cores at 2GHZ, 4GB of RAM and a Linux operating system. Linux with 64 bits is used as the Operating System. Apache is used as the web server. MySQL is used as the database server.

We conduct case studies in the South Bay of the San Francisco Bay Area. Our case studies considered driving, transit and park-and-ride modes of travel. The road geometry data is provided by NavTeq. The transit services include CalTrain, CalTrain shuttles, San Mateo County Transit District (SamTrans), San Francisco Municipal Transportation Agency (MUNI), Santa Clara Valley Transportation Authority (VTA), and the Bay Area Rapid Transit District (BART). Almost all the areas of the South Bay are covered. Several CalTrain parking lots are used to provide the park-and-ride mode. The real-time transit data includes all the routes of CalTrain, SamTrans, MUNI, and BART. We also have the real-time data for a major route of VTA.

Currently, our network includes 241,862 intersections, 313,494 road segments, 9,777 transit stops, 663,565 time points for weekdays, 454,090 time points for Saturday, and 424,712 for Sunday. Our tests show that the trip planning runs very fast and returns results in a few seconds.

The web based client and planning server have been extensively tested by our research group and the Metropolitan Transportation Commission (MTC) of the San Francisco Bay Area. MTC pointed out a large number of issues. Most of them have been solved in our system. The planning server currently provides reasonable trips for most requests.

We now report some results on the response times of our planning servers. First, all the user requests are stored in our logging system. We extract a number of requests from the log files and use them to test the performance of our system. For the transit only mode, the response time is 3.1 seconds, and the standard deviation is 1.4 seconds. For the driving-parking-and-transit model, the response time is 4.7 seconds, and the standard deviation is 1.6 seconds. Table. D-1 and Table. D-2 present the response times for 10 sample requests for transit-mode and driving-parking-and-transit mode respectively.

Table. D-1 Response times of transit only model for some sample requests

Instance	Start Time	Origin Latitude	Origin Longitude	Destination Latitude	Destination Longitude	Response Seconds
1	19:23	37.322170	-122.041620	37.302000	-121.950000	1

Instance	Start Time	Origin Latitude	Origin Longitude	Destination Latitude	Destination Longitude	Response Seconds
2	21:46	37.419427	-121.878737	37.339386	-121.894956	3
3	14:12	37.533013	-122.292976	37.374993	-122.041900	3
4	14:59	37.829256	-122.258332	37.447419	-122.173145	2
5	22:04	37.419169	-122.109400	37.453827	-122.182187	4
6	19:28	37.419169	-122.109400	37.453827	-122.182187	3
7	7:10	37.419169	-122.109400	37.453827	-122.182187	3
8	8:00	37.421132	-122.120457	37.453827	-122.182187	2
9	7:10	37.443087	-122.164417	37.453827	-122.182187	2
10	7:46	37.443087	-122.164417	37.453827	-122.182187	3

Table. D-2 Response times of driving-parking-and-transit model for some sample requests

Instance	Start Time	Origin Latitude	Origin Longitude	Destination Latitude	Destination Longitude	Response Seconds
1	16:12	37.714679	-122.455141	37.481752	-122.258959	2
2	10:06	37.507606	-122.257532	37.580560	-122.347183	1
3	13:43	37.367772	-122.019156	37.313906	-121.937299	2
4	9:28	37.751632	-122.448499	37.494997	-122.249139	3
5	19:54	37.734224	-122.431754	37.539689	-122.310888	4
6	19:54	37.539689	-122.310888	37.734224	-122.431754	4
7	19:55	37.770169	-122.475840	37.490547	-122.254641	5
8	18:09	37.865783	-122.251853	37.470328	-122.149989	3
9	18:13	37.755833	-122.412198	37.865783	-122.251853	5
10	14:01	37.754903	-122.444119	37.464472	-122.165561	4

Appendix E. Case Study of Bus /Train Arrival Time Prediction Algorithm

As a case study, we collected bus operations data, examined operation characteristics, and assessed how real-time prediction can reduce the uncertainties in bus arrival times.

Route SamTrans 390 is one of the most heavily used bus routes operated by SamTrans. It provides schedule-based bus services between Palo Alto Transit Center and Daly City BART along California State Highway 82 - El Camino Real.

Portable GPS/GPRS devices were installed on 15 SamTrans buses to collect second-by-second bus movement data. The collected data were then processed to be projected onto the route, matched with schedule runs, and grouped in terms of run numbers. Figure. E-1 plots trajectories of 102 bus trips in the time-space diagram. These bus trips are for weekday northbound service, which is scheduled to leave Palo Alto Transit Center at 2:18pm and arrive at the destination –

Daly City BART, at 4:27pm. The circles on the plot pinpoint the locations and schedules at the 11 time points.

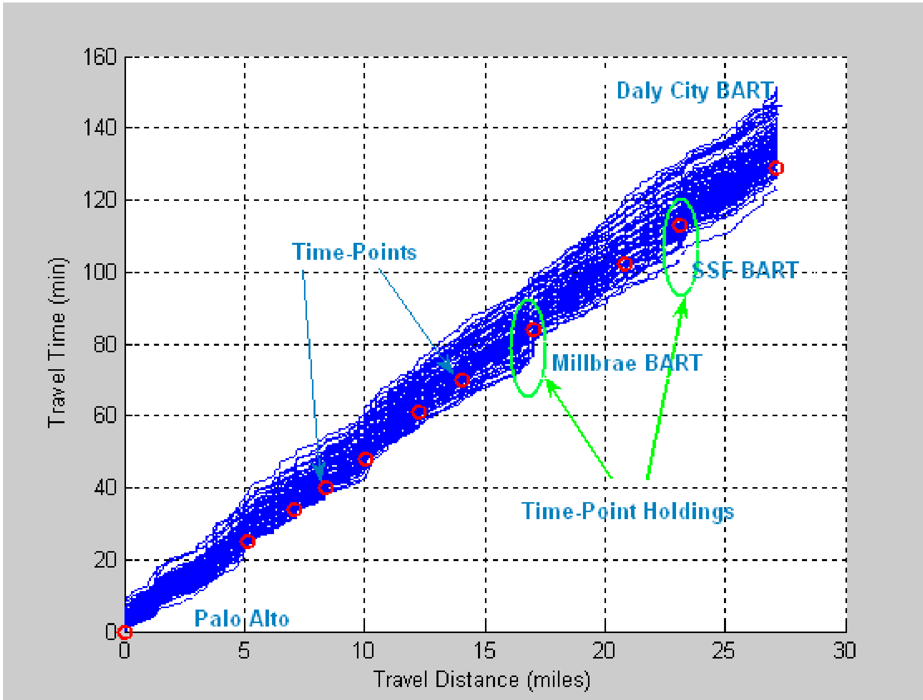


Figure. E-1 Bus Trajectories

Figure. E-1 shows several interesting bus operational characteristics. The variance of bus travel time becomes larger when the bus is further into the trip and the bus is likely running behind schedule. When arriving earlier at a time point, the bus will wait at the time point until the stated time in the route schedule – the so called time point holding phenomenon. This time point holding phenomenon is most observable at the Millbrae BART stop and the South San Francisco stop. The longest holding time observed at these two time points is 6 and 8 minutes, respectively.

Correlation analysis showed that schedule deviation at downstream time points is strongly correlated with the schedule deviation at the last time point and the dwelling time at the time point is not correlated with the experienced delay. Inspired by these findings, we examined the performance of the following regression based model in dynamical estimation of bus arrival and departure time.

Let $s_i, i=1,2,...,n$ denote the schedule departure time at n time points, τ_k denote the schedule deviation at the last time point, $k=1,2,...,n-1$, e_j and d_j denote the estimates of arrival time and departure time at time point $j=k+1,...,n$. The prediction model is formed as

$$\hat{\tau}_j = \alpha\hat{\tau}_{j-1} + \beta(s_j - s_{j-1})$$

$$d_j = s_j + \hat{\tau}_j \qquad j = k+1,...,n$$

$$a_j = d_j - w_j$$

with $\hat{\tau}_k = \tau_k$. The underline meaning of this model is that, given the observed schedule deviation at the last time point (*k*), the expected schedule deviation at individual downstream time point (*j*) is a weighted combination of two elements: the schedule travel time from time point *k* to time point *j* and the experience delay at time point *k*. The weightings α and β are model parameters which can be estimated with historical trip data. w_j is the dwelling time at time point *j* and can also be estimated from trip information. The performance of this model is shown in Figure 4-8. As a comparison, Figure 4-8 also shows the performance of using schedule as the basis for the estimation.

Appendix F. Outreach Efforts

1. Technical Paper Presentations

L.P. Zhang, et al., **Design and Implementation of a Traveler Information Tool with Integrated Real-time Transit Information and Multi-modal Trip Planning**, *TRB Annual Meeting*, 2011, also to appear on Transportation Research Record

J. Q. Li, K. Zhou, L.P. Zhang, W.B. Zhang, **A Multi-modal Trip Planning System Incorporating Park-and-Ride Mode, Real-time Traffic/Transit Information and Customized Alerting Methods**, *ITS World Congress 2010*, Busan. **Won outstanding paper award**

Wei-bin Zhang, Kun Zhou, James Misener, Liping Zhang, Jingquan Li, **IntelliDrive: Establishing the New Foundation for Innovating Transit Safety**, Accepted by *TRB Annual Meeting, 2011*

L. P. Zhang, et al., **Connected Traveler- toward the field testing of a multi-modal mobile traveler information system**, *ITS World Congress 2010*, Busan,

2. Flyer used at Caltrain stations and distributed by agencies

PATH 2Go

ITSBerkeley Institute of Transportation Studies

JOIN UC BERKELEY'S FIELD TEST

FREE REAL-TIME TRAVELER INFORMATION DELIVERED TO YOUR MOBILE PHONE OR INTERNET CONNECTION

WHAT DOES PATH2GO OFFER?

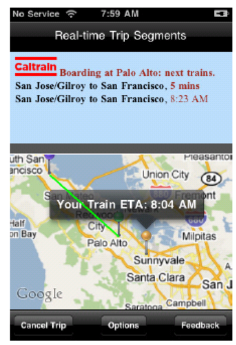
PATH2Go gives you real-time information to enable you to reduce waiting time, relieve stress, and help the environment. Access PATH2Go via http://www.networkedtraveler.org

PATH2Go Trip Planner

- *Compare driving, transit, driving to transit, and bicycling options*
- *Choose among travel options based on current travel time, fare, and carbon footprint*
- *Send trip plan to your smart phone*

PATH2Go Smart Phone Application

- *Available on iPhone, Windows Mobile smart phones and (coming soon) Android with GPS*
- *Search for real-time bus arrivals at nearby stops*
- *Plan your transit trip on your phone*
- *When you're waiting at a station, get an alert about the approach of your train or bus*
- *When you're on a train or bus, get an alert as it approaches your destination*



A screenshot of PATH2Go mobile phone interface

PATH2Go Web-Based Transit Information

- *Find out precisely when your bus or train will arrive*
- *See parking availability at selected Caltrain parking lots*
- *Search for arrival info using route name, stop name, or nearby address*
- *Set up one-time or recurring reminder of train or bus arrivals at your favorite stops via email or SMS*

PROJECT OVERVIEW

The Networked Traveler research project offers travelers an innovative web-based trip planner and mobile applications, based on real-time information about conditions on US101, Caltrain, BART, buses operated by SF Muni, SamTrans, and VTA (Line 522), and selected Caltrain parking lots.

Researchers will evaluate, through the experiences of volunteers like you, whether and how real-time information can encourage and assist travelers to make better travel decisions.

PROJECT PARTNERS

This research is conducted by the California Partners for Advanced Transit and Highways (PATH), Institute of Transportation Studies at University of California, Berkeley, partnering with:

- Research and Innovative Technology Administration (RITA), U.S. Department of Transportation
- California Department of Transportation (Caltrans)
- Metropolitan Transportation Commission (MTC)
- Santa Clara Valley Transportation Authority (VTA)
- San Mateo County Transit District (Samtrans) and Caltrain
- NAVTEQ
- ParkingCarma
- SpeedInfo

HOW DO I PARTICIPATE

Sign up: *Visit the Networked Traveler website www.networkedtraveler.org* and create an account.

Download phone apps: *iPhone, Windows Mobile Smart Phones and (coming soon) Android phones .*

Provide Us with Feedback: *Registered users can take a survey on the Networked Traveler website and be entered into a monthly drawing for a $100 gift certificate.*

For Questions *Contact* path2go@lists.berkeley.edu

Visit the Networked Traveler Website http://www.networkedtraveler.org

Figure. F-1 Design of Path2go flyer

3. Link on MTC 511.org website

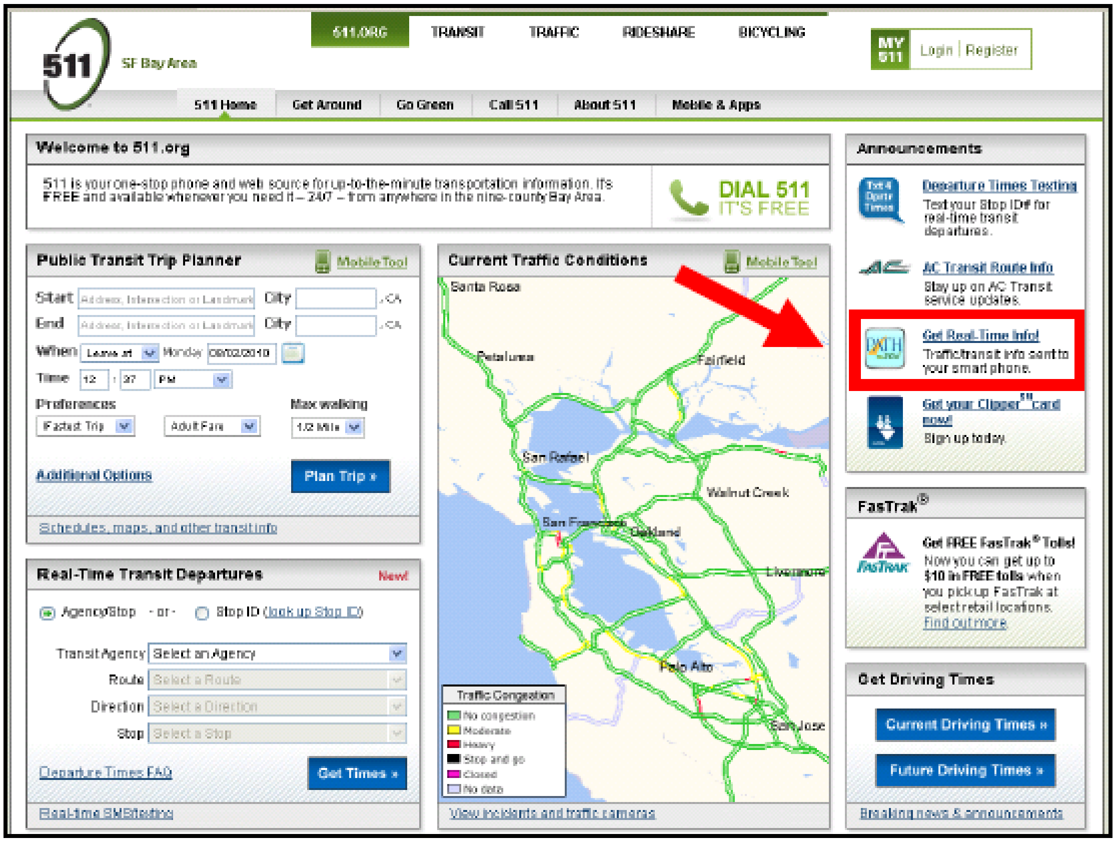


Figure. F-2 Application Launch on MTC 511.org website, active for about two months (screenshot courtesy of independent evaluation report)

4. Link on MTC 511.org third party applications website

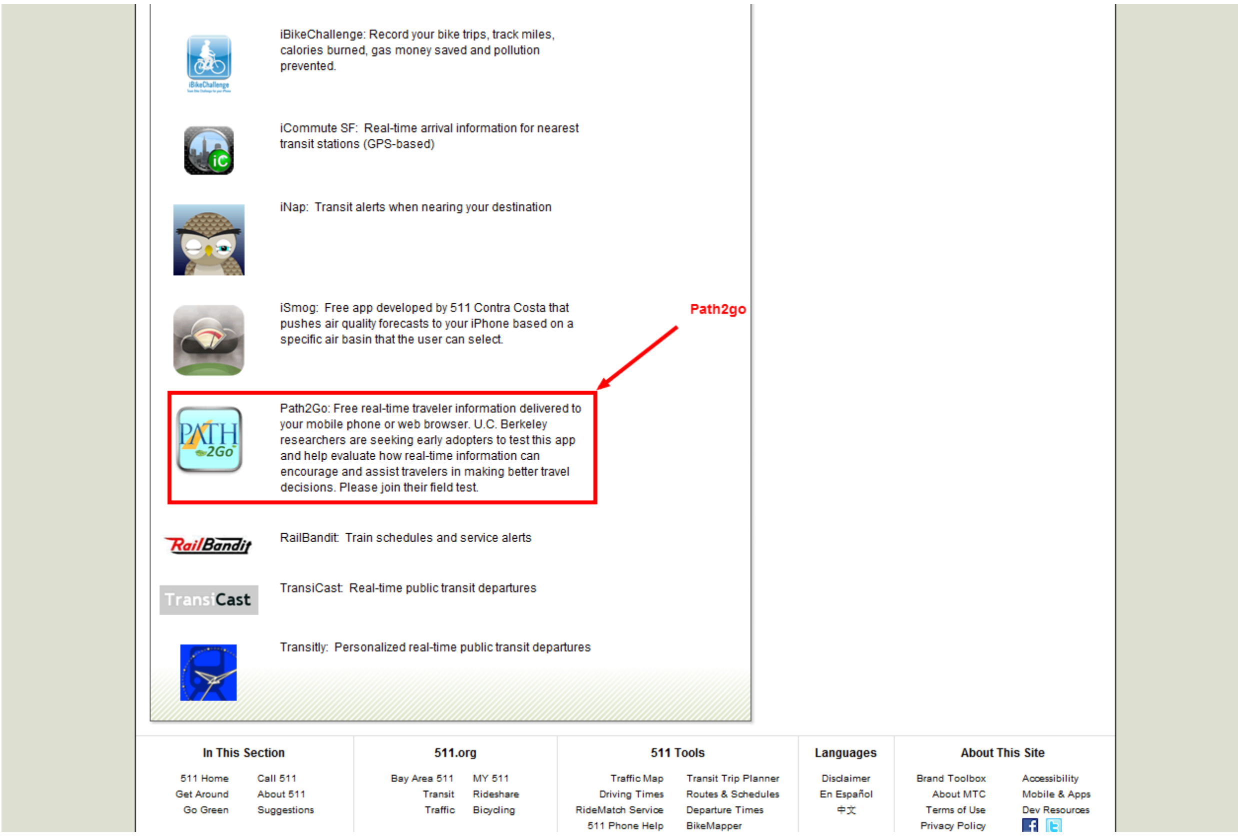


Figure. F-3 Link to Path2go at 511.org – third party mobile apps (active since launch of the project and persistent till then)

Appendix G. System testing results for AVL Performance

Figure. G-1 shows the cumulative distributions of instantaneous throughput. It shows that the instantaneous rates (regardless of the communication outage) of the AVL modem are highly probable to be greater than 335B/s most of the time. While the required throughput for second by second GPS data is less than 100B/s (general length of raw GPS sentence). This rate is accomplished with a probability of over 96%, while rates higher than 335B/s over 90% of the time can be sustained over the long term when outage and other losses are taken into account.

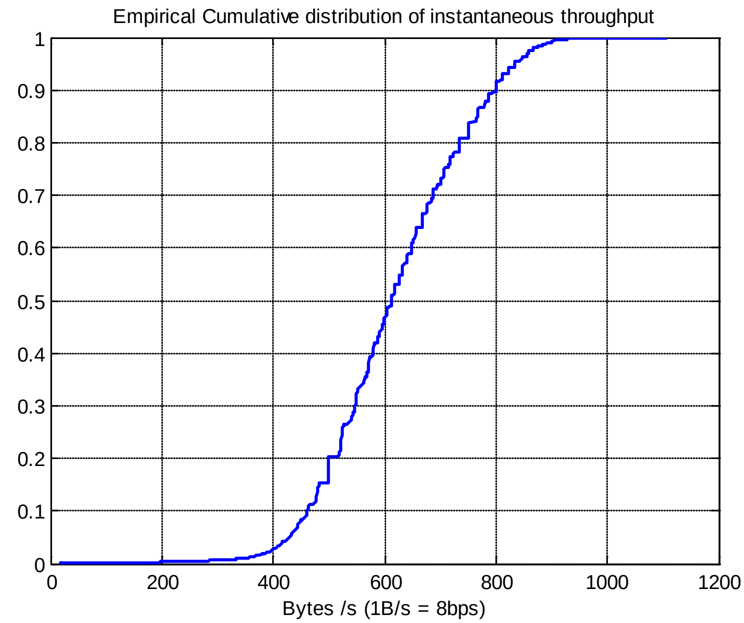


Figure. G-1 Cumulative distribution of the instantaneous throughput (Bytes/s)

Service availability is defined as the number of bytes received by the data center divided by the total number of bytes the original signal controller sent to the client (cell phone). It is always less than 1.0. From Figure. G-2, we see that the probability of data lost due to flow control being greater than 2% is only 2%.

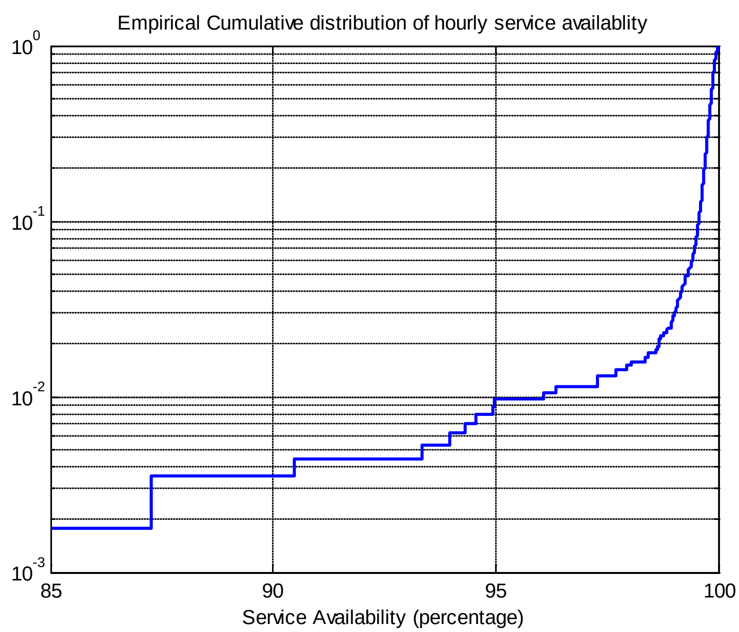


Figure. G-2 Hourly system service availability

The end-to-end latency is measured by the time difference of the GPS UTC time and the recorded time at the data server.

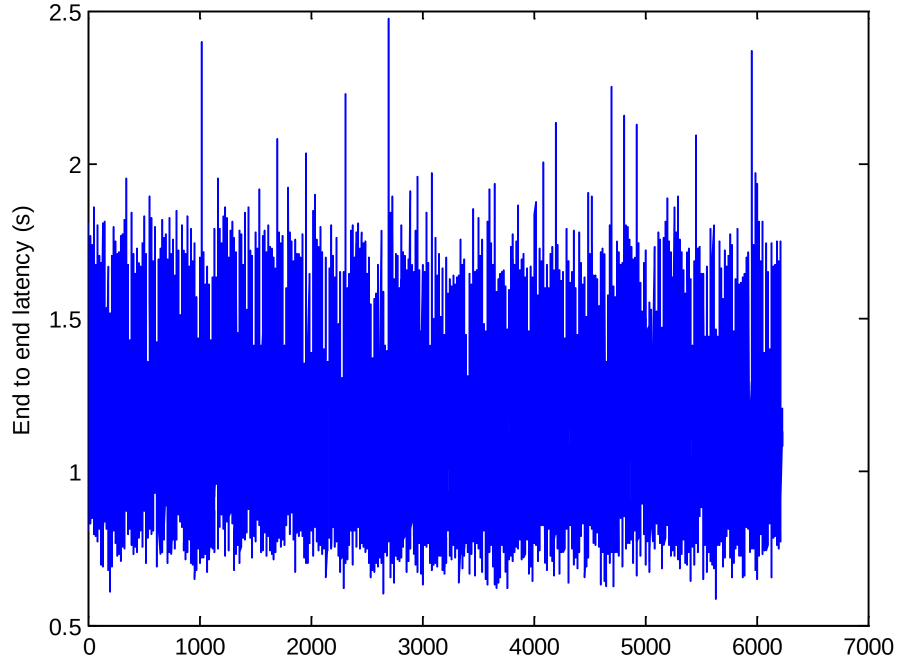


Figure. G-3 The End-to-End Latency of AVL Data

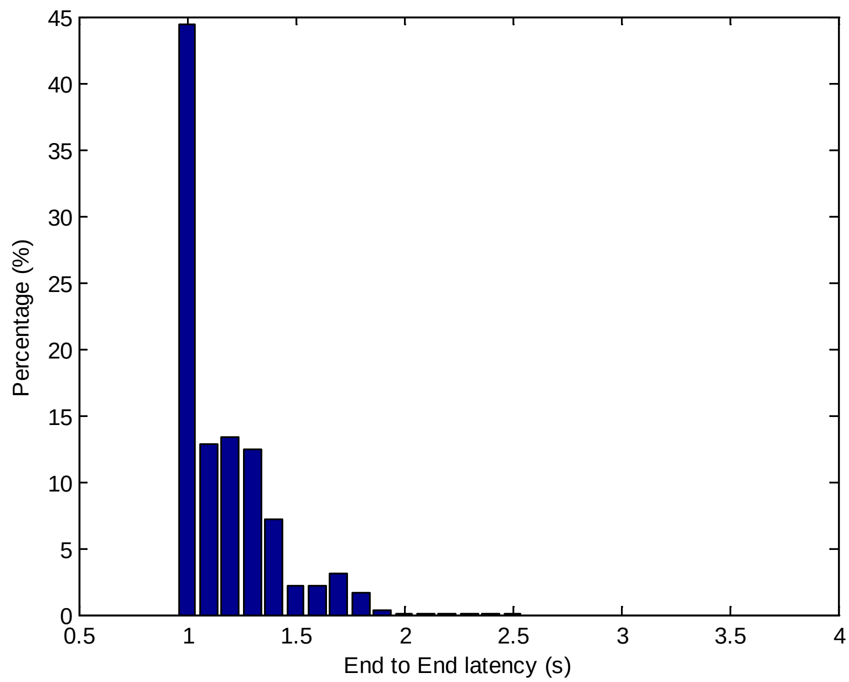


Figure. G-4 Histogram of the End-to-End AVL Data Latency

Statistics showed that (Figure. G-3 and Figure. G-4) end-to-end latency of AVL data is less than 2 seconds for over 98% of the packages. Considering the requirement for the NT transit service, the 2 second latency is within the acceptable range.

In addition to the end-to-end latency, we also need to measure the percentage of outages which is defined as the time period that the device loses network connectivity due to a wireless networking issue, or due to the GPS blockage by buildings, trees, etc. This is measured separately for Caltrain and the VTA buses since they run on different routes (Figure. G-5 to Figure. G-8). The Caltrain locomotives go through several tunnels during their route so there are more GPS outages.

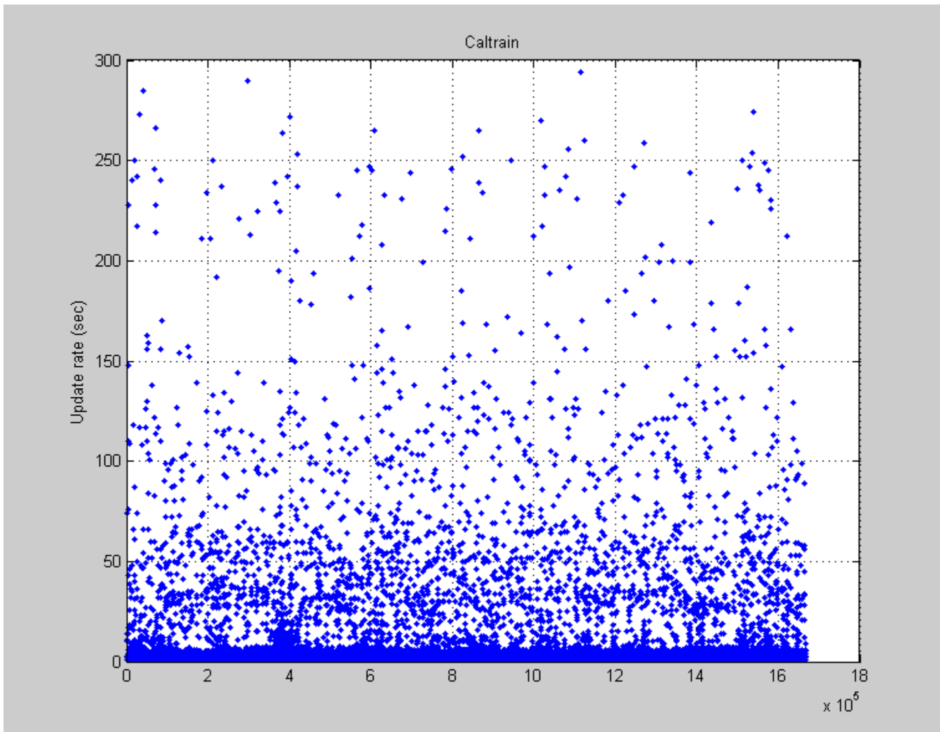


Figure. G-5 Caltrain GPS Outage Occurrences

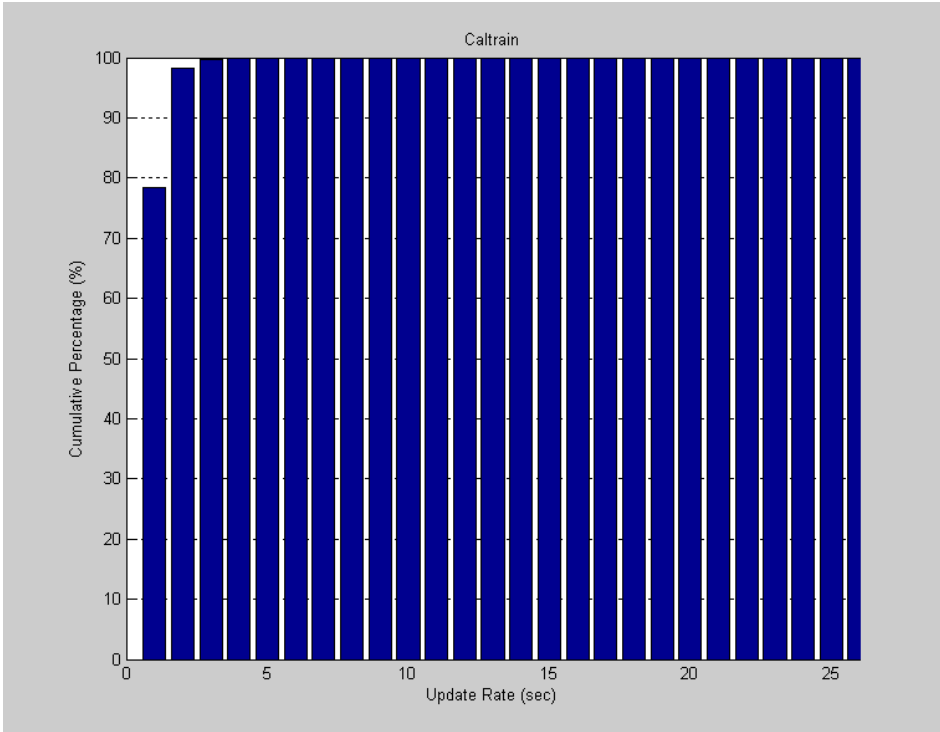


Figure. G-6 Statistics of Caltrain GPS Outage

From Figure. G-6 to Figure. G-8 we observe that with over 98 percent of the packages received on the server, they have a gap from the last sample of less than 3 seconds, or in another words, less than only 2% of the GPS packages received on the server have a gap of more than 3 seconds.

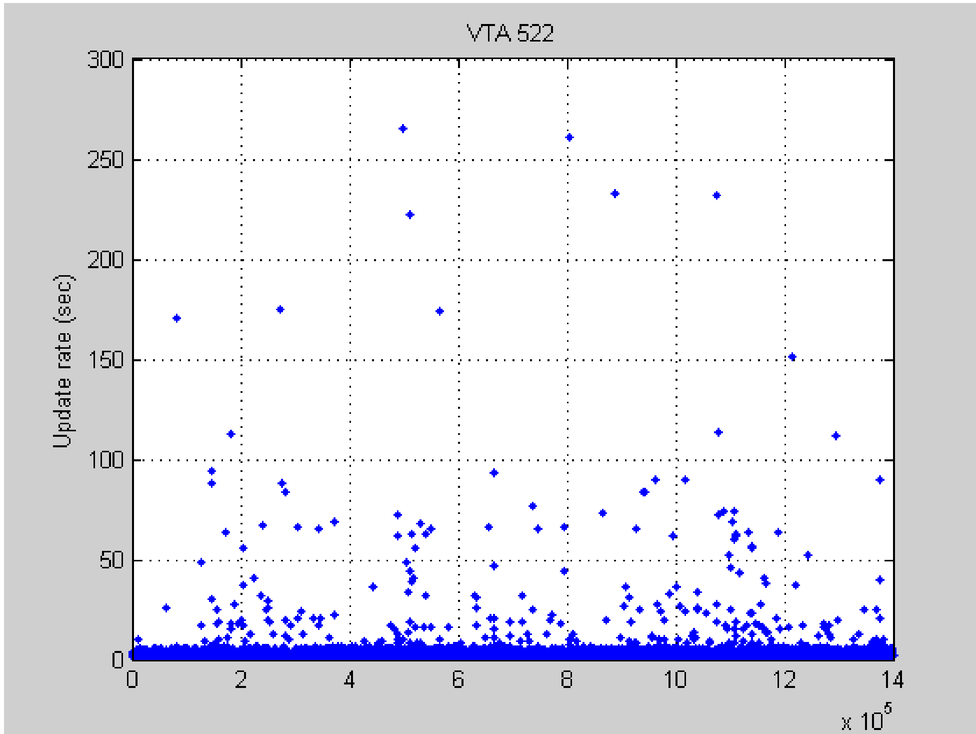


Figure. G-7 VTA 522 GPS Outage Occurrences

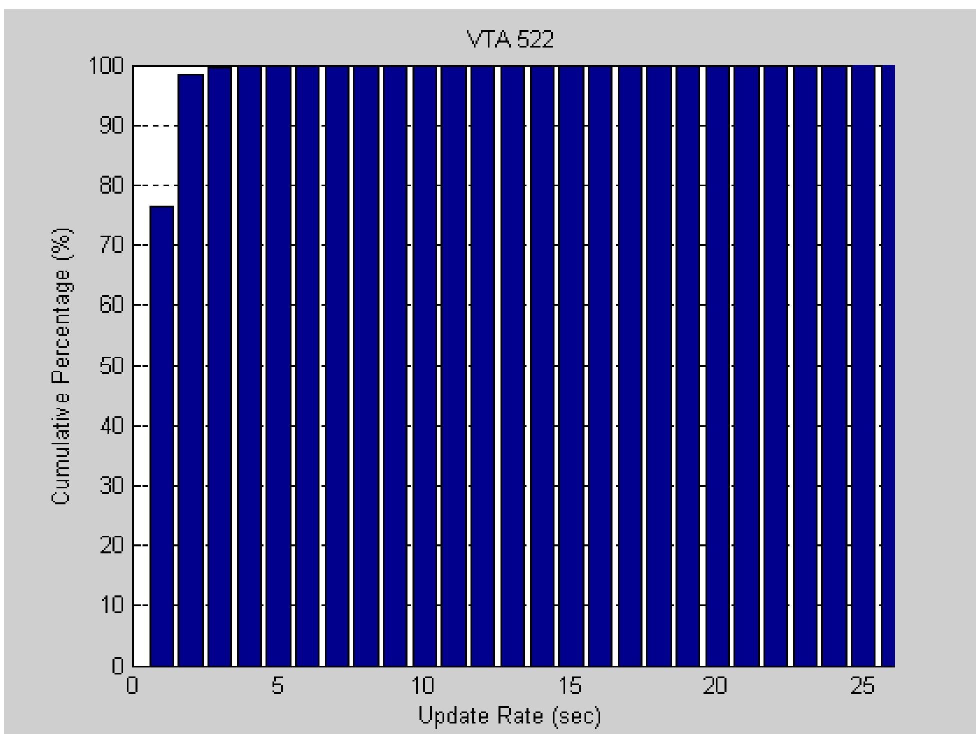


Figure. G-8 Statistics of the VTA 522 GPS Outage

For VTA the outage statistics are even better (Figure. G-8). Both the VTA and Caltrain AVL data outage probabilities meet the requirement for NT transit services.